TERMINATION OF THE MER-DE-GLACE OF CHAMOUNI, AND SOURCE OF THE ARVEIRON.

THE

STORY OF ICE

IN THE

PRESENT AND PAST.

BY

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WITH THIRTY-SEVEN ILLUSTRATIONS.

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PREFACE.

DURING recent years considerable attention has been paid to the phenomena exhibited by ice in the Far North. The discoveries and investigations made by the various expeditions have thrown great light upon many of the much-disputed questions connected with the traces of similar phenomena in the past. In this book an attempt is made to describe the chief features of ice-action, both as they can be observed on the surface of the globe at the present day, and as they appear to have operated in past times, in a manner suitable to those who have not previously studied the subject.

For those who wish for further information the best books are "Greenland Icefields," by Dr. G. F. Wright, D.D., and Warren Upham, A.M.; "Man and the Glacial Period," by G. F. Wright; and "Icework: Present and Past," by Professor Bonney, F.R.S. "The Great Ice Age," by Professor James Geikie, F.R.S., is a valuable book for reference.

My best thanks are due to Mr. E. J. Gar wood for the loan of photographs of Alpin

and Spitzbergen scenery, from which some of the illustrations have been prepared; and for revising the proof-sheets. I am also indebted to the Royal Geographical Society for the loan of the blocks from which Figs. 14 and 15 were taken. Figs. 30 and 31 are from Sir John Evans' "Ancient Stone Implements of Great Britain."

W. A. B.

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CHAPTER I.

INTRODUCTION.

Ice, in the various forms in which it is found upon the surface of the globe, not only plays a large part in the economy of Nature, but has many important relations to human affairs and conditions of existence. The Swiss mountaineer must build his châlet out of reach of the avalanche, and must beware of the snow-hidden crevasses on the glaciers. The navigator in the path of icebergs must steer his ship with caution, and in the Polar Oceans must be alive to the dangers of the ice-pack. A heavy fall of snow may break down telegraph wires, and disorganize traffic and commerce to an immense extent. Less obviously the work of ice, but in many instances not less important to mankind, are effects which have been recognised as due to the glaciers and ice-sheets of the past. Formerly many of the now fertile and populous countries of the Northern Hemisphere appear to have been subjected to conditions of cold only to be paralleled at the present day on lands within the Arctic Circles. Some of the changes brought about during this period were of but a temporary nature and disappeared with the

melting of the ice; others were more permanent, and exercise important influences on the surface of the world to-day. The celebrated Falls of Niagara, for instance, owe their formation indirectly to the action of the glaciers which once spread over the greater part of North America. In the first of the two parts into which this book is divided, an attempt is made to describe the chief phenomena manifested by ice on the surface of the globe at the present day. The second part deals with the effects produced by ice during the past history of the world.

In order to understand the behaviour of ice in large masses, such as those which constitute glaciers or ice-sheets, it is necessary to be familiar with the various changes which take place during the act of freezing, and the fundamental properties of the ice formed. We shall, therefore, commence by studying the behaviour of a piece of ice, such as could be held in the hand, describing as far as possible, experiments by which its structure, plasticity, property of contraction on melting, and other characters, can be exhibited. From these simple facts we shall go on to consider the modes of formation, so far as they are known, and the behaviour, of the atmospheric forms of ice, hoar-frost, hail, and snow, and the parts they play in nature both as agents of destruction and preservation. The subject of snow leads us up to the study of glaciers, which constitute the channels of escape of the excess of snow accumulated on lofty plateaux or in

the hollows among the mountain peaks. The glaciers of Switzerland, the scenes of the labours of Agassiz, Forbes, Tyndall, and other earlier workers, for a long time furnished most of our information concerning these rivers of ice. But in recent years it has come to be recognised, that the glaciers of the Alps are but small compared with the great masses of ice which creep down many of the valleys of countries nearer the Pole. The explorations of Mr. I. C. Russell, of the United States Geological Survey, among the glaciers of Mount St. Elias, in Alaska, and of Mr. E. J. Garwood and Dr. J. W. Gregory, in Spitzbergen, have placed us in possession of a number of new and interesting facts, and in some cases have considerably modified the views as to the effects a glacier is able to produce.

From an account of the large glaciers of Spitzbergen and Alaska, to the consideration of the great ice-sheets, which almost or entirely cover many of the lands within the Arctic and Antarctic Circles, is but a step. Here, again, much of our information has been acquired from explorations of the Arctic regions made during recent years. The largest ice-sheet in the Northern Hemisphere was, in August and September, 1888, traversed from east to west by Dr. Fridjof Nansen and five companions, the narrative of his journey being admirably told in "The First Crossing of Greenland." In 1892, Lieutenant Peary undertook, and successfully carried out an

even more adventurous expedition, travelling in sledges some 1,300 miles over the ice in Northern Greenland. In his several journeys he has practically completed the delineation of the north coast of that ice-bound country.

So far we shall have been dealing with forms of land-ice, but now the phenomena which floating ice, whether on river, lake or sea, gives rise to, will claim our attention. With the general features of the Arctic seas we have long been familiar, from the voyages, and discoveries made by the hardy seekers after the North-West Passage. But, as regards accurate scientific information, no previous expedition has been so fruitful as that from which Dr. Nansen has recently returned. The Arctic Ocean, formerly believed to be a shallow basin, was shown to be a sea of great depth. The belief in the existence of a never-melting ice-cap covering the Pole was shown to be erroneous, the whole mass being in a state of slow movement towards the outlet in the North Atlantic. Upon the direction of flow of certain ocean-currents, the very existence of which was previously only surmised, the whole conduct of the expedition depended. The complete success of his project proved the accuracy of Nansen's views. Besides these more important discoveries, numerous other scientific observations were made.

Our examination of the various forms of ice-work which may be seen in operation upon the globe at the present day, will have put us

in a position to recognise traces of similar action in the past. To those who have not studied the subject, it may at first seem a hopeless task to look for signs of glaciers and ice-sheets which disappeared, perhaps many thousands of years ago. For will not vegetation have covered up and concealed their effects upon the rocks, and will not storms, rivers, and floods, long since have swept away any accumulations they may have left behind? This is very largely the case; yet we shall be able to show that many of us live in countries where the traces of the vanished glaciers lie at our very doors, in some cases so fresh and distinct that but little effort of the imagination is required to reconstruct the scene. We shall learn that at no very distant date, geologically speaking, the Northern Hemisphere was subjected to the most extraordinary vicissitudes of climate; that, from warm and indeed almost tropical conditions, the temperature gradually declined, until snow and ice held universal sway. This remarkable period is known to geologists as the Ice Age or Glacial Epoch.

One of the most interesting chapters in the story of the Ice Age is that dealing with the various forms of life which flourished while it prevailed. This arises, partly from the strange and unfamiliar character of many of the animals which roamed over Europe and America at that time, but more from the fact that the early history of mankind extends over the period. Any discovery which tends to throw light upon the origin of the human

race, possesses a singular fascination for us. The finding of implements and other traces of primitive man, beneath deposits accumulated during the Glacial Period, carries the date of his appearance on the globe far back into the past.

No period in the history of the earth has been so much discussed, or has received so much attention from geologists, especially in recent years, as the one we are about to describe. Yet, despite this fact, the subject is one which bristles with disputed points. As far as possible, controversial details will be avoided in this book; but, in cases where the difference of opinion concerns a matter too important to be omitted, the arguments on each side of the question will be briefly given.

The question as to the cause of the Glacial Period well illustrates the difficulties of the subject. Although the problem has been attacked by the most eminent geologists and astronomers, and numerous theories and suggestions have been made, yet the fact remains, that we are still in ignorance of the exact cause, or causes, which brought about this great lowering of temperature over so large an area of the globe.

In the last chapter, an account is given of the traces of ice which have been discovered in periods earlier than the Glacial Epoch. We shall see that in the far distant past, long before man had appeared, before probably mammals at all were upon the globe, there is evidence of a wide-spread incursion of ice, in

the Southern Hemisphere. To-day, the records of these ancient glaciers are found in India, Australia, and the Cape, beneath a blazing tropical sun.

Ice in the Present.

CHAPTER II.

THE PROPERTIES OF ICE.

EVERYONE is familiar with the fact that most solid substances, when heated, if they are not burnt or broken up into simpler bodies, eventually become liquid; but that the temperatures to which they have to be raised in order to bring about this result, vary very considerably. Quite a low heat, for instance, will cause grease to become liquid, lead can be melted fairly easily, but iron must be raised to a very high temperature before it becomes molten; on allowing these substances to cool they again become solid. Now to the solidification of water when sufficiently cooled, we have chosen to apply a special term, viz., *freezing*, but, although we do not use this word to describe the solidification of molten iron or lead, nevertheless, precisely the same process occurs in each case.

Let us imagine we have a block of ice, and let us try to ascertain from experiments with

it, what are the chief changes which water undergoes, when it passes from the liquid to the solid state.

Break some of the ice up into small pieces, and place it in a vessel around the bulb and stem of a thermometer. The mercury in the latter at once falls to freezing point. Now gently heat the vessel by means of a spirit lamp, and thus gradually melt the ice. This may take a considerable interval during which heat is passing into the water, but no rise of temperature is indicated by the thermometer, until the last particle of ice has melted. This disappearance of heat may also be shown by mixing a pound of crushed ice, at freezing point, with a pound of water warmed to 80° C. The ice is completely melted, but all the heat from the warm water is absorbed in the process, the resulting two pounds of water being at freezing point.

We see, then, that in the change from ice to water a considerable amount of heat is absorbed, or becomes *latent*. But it is easy to show that in the reverse change, viz., from water at freezing point to ice at freezing point, a considerable amount of heat is given out. Under proper precautions, water can be cooled down very considerably below freezing point without solidifying. But if now the water be agitated, it at once freezes to a solid mass. The temperature of this ice, however, is freezing point; that is, the heat evolved in the process of freezing has been sufficient to warm

the water from perhaps 10° or 15° below freezing point, up to that temperature.

The property, which ice and other solid substances have of absorbing heat when they liquefy, is extensively made use of in freezing mixtures. If salt be mixed with crushed ice or snow a portion of the mixture becomes liquid, and in the process absorbs so much heat from the rest, as to cool it down perhaps 20° below freezing point, if the proportions of the constituents are favourable. Farenheit erroneously thought that with the aid of freezing mixtures he had produced the greatest degree of cold possible, and he accordingly took this temperature as the zero of the thermometer which bears his name. Though based on a misconception, this scale is extensively used in English-speaking countries.

A very pretty and simple experiment was devised by Professor Tyndall to show that ice possesses structure. If a plate of ice, the surfaces of which are parallel to the original plane of freezing, be placed in the path of a sunbeam or a ray of heat from any source, the passage of the latter through the ice will soon be marked by a number of bright little glittering points. When examined under a lens, each of these little points is seen to consist of a most perfectly-formed six-rayed star. Professor Tyndall very appropriately gave the name "Ice-flowers" to these figures. They consist simply of little cavities filled with water, formed by the melting of a single ice-crystal. These crystals, of which the

whole block throughout is composed, are made by the ultimate particles of water arranging themselves in certain definite forms. They vary somewhat in size and outline, but are all built up upon the same fundamental plan, and each one shows the six-rayed structure.

A form of ice, in which the crystalline structure can be very easily observed, is snow.

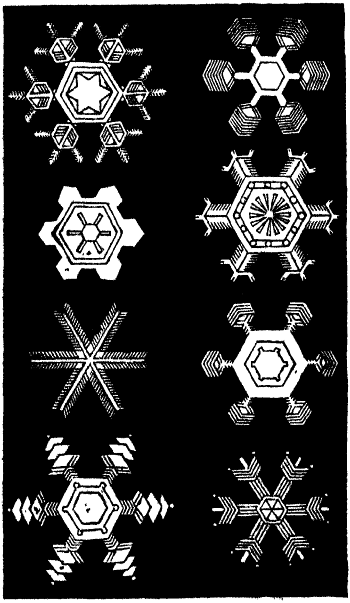

FIG I.—SNOW CRYSTALS

If a few flakes of snow be caught on a black surface during a calm day, and examined under a lens, they will be seen to consist of little needles of ice grouped into symmetrical forms often of great beauty (Fig. 1). Although upwards of a thousand different figures have been observed, they are all variations of the same star-like form. In the feathery figures which are formed on the window-panes in frosty nights, the same tendency to crystallisation is shown. In this case the symmetry is rarely so complete, but nevertheless, the angle between the little shoots and branches is the same as that between the rays of the star, or the petals of the ice-flower.

Perhaps the most important property which water displays as it passes into ice, is the very marked expansion which occurs at the moment of solidification. The amount of this expansion is about 10 per cent, or to put it in another form, 10 cubic feet of water becomes 11 cubic feet of ice. We are most of us familiar with the effects of this expansion in our dwellings, although we do not always attribute these effects to the right cause. When, at the end of a period of frosty weather, the water-pipes are found to be broken and leaking, the thaw is often regarded as the agent which has wrought the mischief. This is incorrect; the pipes are really broken long before by the expansion of the water on freezing, but the fracture is closed by the ice, and it is not until a thaw comes that the

damage is discovered. Jugs and other vessels containing water are often split by this action.

The question will occur to many readers, what would happen if water were subjected to the action of frost in a completely-filled, closed vessel, so that it had no room to expand. Under these circumstances the pressure exerted by the water is enormous, and in order to resist it, and prevent ice from forming, the vessel must be one of very great strength. Major Williams made some interesting experiments on this subject in Canada. He filled two 13-inch iron bomb-shells with water, and firmly closed the touch-holes with iron plugs. They were then exposed to the action of frost. In one case, after some time, the iron plug was forced out with a loud explosion, and thrown to a distance of over 400 feet, a cylinder of ice, eight inches long, issuing from the opening. In the second case, the shell was burst before the plug was driven out, and a collar of ice was formed all round the fracture.

Water undergoes another change of volume which, though far less in extent than that we have just been considering, nevertheless plays a very important part in the economy of Nature, and must not be lost sight of. This is an expansion which occurs immediately before freezing, while the water is still liquid. Suppose we take boiling water and let it cool gradually, it contracts slightly, but continuously until it has reached a temperature only a little above freezing point.

This temperature is marked 4° on the Centigrade thermometer or 39·2° on the Farenheit scale. No further contraction occurs, and the water is now at its maximum density, or, to put it more simply, is at its heaviest. If the cooling is continued, it *expands* slightly for the next 4 degrees, until it reaches the freezing point, when, as we have already seen, a very much greater expansion suddenly occurs.

The following experiment has been employed to exhibit this property of water:—A long glass vessel, pierced by two apertures one at the bottom and one at the top, in which are fixed thermometers, is filled with water at freezing point and brought into a

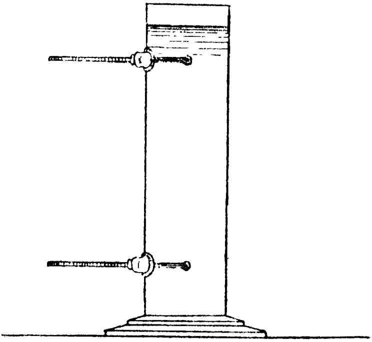

FIG. 2—EXPERIMENT FOR SHOWING THE MAXIMUM DENSITY OF WATER

warm room (Fig. 2). As the layers of liquid

in contact with the sides of the vessel become heated, they sink to the bottom, and for some time the lower thermometer marks 4° C. while the upper one remains at zero. The inverse experiment of filling the vessel with warm water, and bringing it into a room maintained at freezing point can also be made. In this case the lower thermometer having sunk to 4° C. remains at that temperature, while the upper one cools down to zero. Each experiment indicates the fact that water is heavier at 4° C. than at any other temperature.

These two phenomena which water exhibits, viz., its expansion just before freezing point, and its further expansion on passing into ice, exert a great influence upon the physical conditions of the surface of the globe. It is owing to these expansions that deep lakes and rivers are rarely frozen, and shallow ones, even in the severest winter, only to a comparatively small depth; for as soon as the water on the surface in contact with the air is cooled down to 4° C. it sinks to the bottom and a fresh layer takes its places. A series of currents is thus set up between the upper and the deeper layers and no further cooling of the surface can occur until the temperature of the whole body of water in the lake has been reduced to 4° C. When once this condition has been attained, the lake is soon frozen over, as the cooled water is now the lighter, and remains on the surface. But the ice thus formed, in virtue of the further expansion which takes place at the moment

of freezing, is lighter than the water, and in consequence it floats upon the latter, and tends to protect it from further cooling. Growth in the thickness of the layer of ice consequently takes place very slowly, and fish and other organisms are able to live in the deeper parts of the lake which still remain at 4° C. Suppose this expansion of water on freezing did not take place, but that on the contrary a contraction occurred. In this case the ice formed on the surface would at once sink to the bottom, and a fresh layer of water would be exposed. Hence in a very short time the lake would be frozen to a solid mass, to melt which, the entire heat of the summer would not suffice.

Another important result of the force exerted by the expansion of ice, is the disintegration of rocks and soil, which, in high latitudes especially, takes place to a great extent. Water collects in the little crevices and fissures of the rocks, and the great pressure set up when it freezes, is often sufficient to burst asunder huge blocks of stone. On cliffs and hillsides, large masses of rock are split off, and rolled down to the foot, there to be further broken up by the same action. The effect of oft-repeated frosts upon the surface of the ground is to produce a characteristic type of scenery well displayed in the higher parts of mountain ranges and in countries near the Poles (Fig. 3 and Fig. 6). The smooth, undulating curves which result from denudation by rain and rivers are

FIG. 3.—THE MATTERHORN. TO ILLUSTRATE THE TYPE OF SCENERY PRODUCED BY THE ACTION OF FROST.—*Garwood.*

replaced, where the frosts are severe by sharply-cut outlines and rugged precipices. Everywhere the rocks have been chiselled into crags, pinnacles, and ridges, at the bases of which great heaps of loose material accumulate. In Spitzbergen and on the west coast of

Greenland, the screes formed of fragments split off from the cliffs during the keen winter frosts, sometimes attain enormous dimensions

FIG. 4.—SCREES FORMED OF ROCK-FRAGMENTS SPLIT OFF FROM THE CLIFFS BY THE ACTION OF FROST.

There are several conditions under which the freezing point of water is lowered; that is to say, water remains as water at a temperature at which, under ordinary circumstances, it would immediately become ice. As all or most of these conditions occur in nature, and bring about results of considerable importance, we must briefly consider them.

Increase of pressure is one of the conditions which produces a lowering of the freezing

point of water. If water is subjected to a pressure of about 2,000 pounds to the square inch, it does not freeze until the temperature is one degree *below* the normal freezing point; or conversely, if a block of ice at 1° C. be subjected to a pressure of 2,000 pounds, it melts without any rise of temperature. Major Williams' experiment described on page 25 has already furnished us with one instance of the relation between pressure and lowering of freezing point. In this case the pressure which maintained the water as a liquid until the moment the shell burst, was produced by the attempt of the water itself to expand within a closed space.

An apparatus which has been employed to show the melting of ice under pressure, consists of a stout steel tube, closed at one end by a screw and at the other by a screw-piston. The tube is filled with water, and a metal bullet is dropped into it, the screw is closed, and the whole apparatus placed in a freezing mixture with the piston end downwards. When the water has frozen, the bullet is pressed against the piston end by the ice. The tube is now removed from the freezing mixture, and inverted, so that the piston end is uppermost.

By gently turning the screw the piston is forced downwards, and thus made to exert a pressure on the ice. When the lower screw is opened, the bullet drops out followed by a short cylinder of ice which is formed at the moment of opening.

A very simple experiment to show the lowering of the freezing point of water by pressure, may be made by placing a bar of ice horizontally between two supports, and suspending, across the centre, an iron wire to the ends of which heavy weights are attached. The iron wire slowly cuts its way completely through the bar of ice, leaving no trace of its passage beyond a few bubbles of air. The pressure of the wire melts the ice beneath it, but the water instantly freezes again behind it, and closes up the space.

Another instance of this property is seen when two pieces of ice at, or near, freezing point are pressed firmly together; whilst the pressure is maintained they are separated by a thin film of water, but when it is removed this film is instantly frozen, and the two fragments form one solid piece of ice. This is the secret of snowball making, the little crystals of ice of which the snow is composed being melted by the pressure into a more or less solid mass. On a very cold day, the snow will not "make"; that is because the hands cannot apply sufficient pressure; but if the snow be held in the hands until it has been nearly warmed up to melting point, it can be pressed into a snowball as usual. The snow-bridges which span wide chasms in Alpine regions, and over which men can walk in safety, are formed in the same manner.

The slow movement of a glacier down the valley which contains it, is materially assisted by the melting of the ice at the points where the pressure is greatest.

Another condition which tends to lower the freezing point of water, is the presence in it of foreign substances, such as salts. Sea-water, for instance, freezes at about three degrees below the normal freezing point, the ice which is formed being quite pure, and a saturated solution of salt remaining. In Finland, sea-water is concentrated by a process of freezing in order to extract salt from it.

Pure water can also be cooled down considerably below freezing point by boiling it, so as to free it from air, and then keeping it perfectly still. The slightest movement, however, causes it to freeze at once. Keeping water in a state of rapid agitation is another method of retarding freezing. Water contained in very fine capillary tubes has been cooled as low as 20° C. without solidifiying. These phenomena probably rarely occur in nature, except perhaps the last, which possibly explains how it is that plants are able to resist a severe degree of cold without being killed, their sap being contained in very fine vessels.

CHAPTER III.

SNOW, HAIL, AND HOAR-FROST.

MOISTURE in the form of vapour is always more or less present in the air even in the dryest climates, and if any of the layers of the atmosphere become sufficiently cooled to freeze it, this moisture may fall to the earth as snow, sleet, or hail, according to the atmospheric conditions which prevail; or may be deposited upon the ground in the form of hoar-frost.

Snow.—As the atmosphere becomes colder in proportion as we ascend from the surface of the earth, a point is ultimately reached at which the temperature is freezing point. Here the aqueous vapour in the air can no longer remain as such, but passes into ice in the form of snow. The height of this point of course varies with the latitude and the season of the year. In England, for instance, in summer, the freezing point is about a mile and a halt from the ground, and it is highly probable that many of the little fleecy clouds, which are seen at a great height in the sky, are above this point, and consist of fine snow; any flakes, however, which fell, would be melted long before they reached the ground. In winter, the level at which snow is formed often comes down to the surface of the earth.

Over the warmer and larger portion of the surface of the globe, snow never falls; in countries within the temperate zones, snow only appears in winter; while in regions near the Poles, snow may fall throughout the year. But even in the tropics, where mountain ranges occur of sufficient height to penetrate into the upper colder layers of the atmosphere their summits may be wreathed in snow.

On those mountain tops which only just reach the cold regions, the winter snows may be all dissipated during the succeeding summer. But in the case of loftier ranges, where snow falls over a large area, the winter accumulation may linger all through the summer and receive a fresh accession the following year; indeed, on the highest parts snow may fall throughout the year. On such mountains it is obvious that the limit to which the snow reaches will vary with the season of the year. In winter it will push its way down the slopes, in summer it will retreat towards the summits; but there is a line at which the two opposing forces, the summer's heat and the winter's snow, just balance each other, and above which the snow never melts. This boundary is termed the *snow-line.*

The height of the snow line above sea level is influenced by many local circumstances, but depends primarily upon the latitude. We can best picture it as a great arch arising from the sea in Arctic and Antarctic regions, and attaining its greatest elevation over the Equator (Fig. 5).

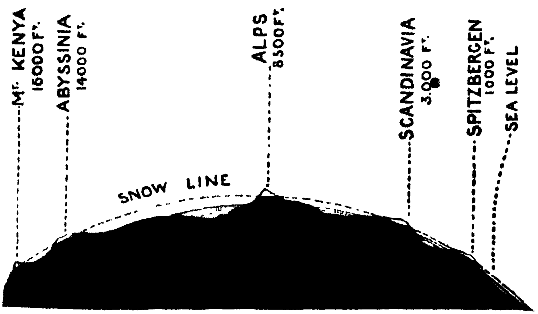

FIG 5.—THE SNOW-LINE BETWEEN THE EQUATOR AND THE NORTH POLE.

In the tropics the snow-line is from 15,000 to 20,000 feet above sea level, and only lofty ranges such as the Himalayas reach it. In the Alps it is from 8,500 to 9,000 feet; and on the north coast of Scandinavia it has come down to 3,000 feet. In Spitzbergen the snow-line is about 1,000 feet up, and further to the north it comes down to sea level.

The height of the snow-line is often very considerably affected by the temperature of the prevailing winds and the amount of moisture they bring to be precipitated in the form of snow. A warm dry wind will tend to raise the snow-line; on the other hand a wind with much moisture may cause the snow-line to fall very considerably below the average height for that particular latitude. A good instance of this is furnished by the Himalayas. On the south side of the range, though

actually nearer the Equator, the snow descends 4,000 feet lower than on the north side. This is owing to the fact that the winds which blow from the south side have passed over the Indian Ocean, and are heavily charged with moisture. The greater part of this moisture is deposited upon the southern slopes in the form of snow, and the wind which passes over the range to the north side is comparatively dry. The snow-line on the north side is still further raised by the hot dry winds which blow across the plains of Thibet.

On lofty tablelands such as those of Norway, and in the gathering-grounds formed among the peaks and ridges of mountain chains, snow often collects in sheets of great extent and thickness. These permanent accumulations have received the name of snow-fields (Fig. 6). Within the Arctic Circle they are sometimes many miles across and hundreds of feet in depth.

Snow-fields being situated above the snow-line, and receiving a fresh accession of snow every year, it would seem that the amount must go on increasing indefinitely. But this is not the case. Two channels of escape are provided for the excess of snow; it may either go to nourish glaciers, or great masses of it may break away, and rush down the slopes in the form of avalanches. Glaciers, the means by which the larger proportion of the snow is carried away, will be more fully considered in the following chapter. Ava-

FIG. 6.—SNOWFIELDS IN THE ALPS. THE WATER-SHEDS HAVE BEEN CARVED BY THE ACTION OF FROST.—*Garwood.*

lanches play only a comparatively small part in draining the snow-field, but their effects upon human habitations and vegetation are often far-reaching and disastrous. In spring and summer, especially, sheets of snow, perhaps hundreds of yards in extent, often break away from their positions, and tumble headlong down the valleys, sweeping away trees, rocks, and homesteads in their progress. In Switzerland and other Alpine Countries, belts of pine forest are often carefully cultivated across the lines of the most frequent snow-falls in order to protect villages and fields beneath them. Besides the damage directly wrought by an avalanche, further harm may result from the blocking of streams or rivers which happen to cross its path. The water accumulates behind the temporary barrier, and ultimately bursts it, giving rise to disastrous floods in the valley below. The sudden movement of a vast mass of snow, perhaps hundreds of thousands of tons in weight, through a narrow ravine, frequently gives rise to a violent blast of wind. Men and animals have been carried through the air, and buildings blown down. On one occasion, a sledge with the driver and horse was swept by the whirlwind for some 300 yards, and then deeply buried in the snow.

Besides bringing about the formation of avalanches, snow acts as an agent of destruction in several other ways. In wooded regions, branches are broken off, and even entire trees borne down, by the weight of the snow which

accumulates upon them. In the Rocky Mountains, a curious result of the combined action of wind and snow has been noticed. The little crystals of ice, of which the flakes are composed, driven at a great rate through the passes act like saws upon the trees, wearing away the bark and foliage, and even cutting into the wood.

The sudden melting of great quantities of snow owing to an abrupt rise of temperature at the end of winter, often causes floods. Rivers rising in mountainous regions are liable to periodic floods from this cause. The Ganges and its tributaries for instance, which draw their supply of water from the snowy ranges of the Himalayas, begin to rise in April, and flood vast plains to a depth of over 30 feet.

But snow does not always act as an agent of destruction; on low-lying ground especially, its chief function is of a conservative nature. The surface of the ground beneath a covering of snow is protected from frost, and vegetation is enabled to live through the winter, though the temperature of the air above may be several degrees below freezing point. In places where the snow has been blown away, the ground is often frozen to a considerable depth. This protective influence of snow arises from the fact that it is a bad conductor of heat, that is to say, heat only passes through it very slowly. The Eskimos who inhabit the barren shores of north-west Greenland, take advantage of this property to build

their huts of snow; although outside the cold may be intense, the warmth inside is sufficient to defy even the icy blasts of the Arctic regions.

The minute structure which a single snow-flake possesses has already been described. The size of a snow-flake depends upon the condition of the atmosphere in which it is formed. During very cold weather, snow falls in minute flakes like a fine white powder, but when the temperature of the air is near freezing point, the flakes are often of a considerable size. In windy weather the delicate structure of snow-flakes is destroyed, and they become broken up, and compressed into a confused mass of icy needles. If the temperature is rising, or if the snow flakes pass through a warmer layer of the atmosphere in their descent, they reach the ground in a half-melted condition, which has received the name of *sleet*. Snow is colourless, although a mass of it always looks white, yet if a single flake be examined it will be seen to be built up of perfectly clear, transparent crystals of ice. The white colour is really produced by reflections from innumerable minute surfaces of ice. For the same reason the powder produced by crushing a piece even of the clearest glass always appears white.

Hail consists of compact globules, usually formed by concentric layers of ice deposited round a core of compressed snow. Hail-stones vary in size from the dimensions of a small pea to those of a pigeon's egg, or even

larger. The exact manner in which they are formed is not perfectly understood, but it is probably connected with electrical disturbances in the atmosphere, as hail often precedes or accompanies thunderstorms, and falls more frequently in summer than in winter. When the hailstones are of large size, a shower frequently causes great destruction, devastating crops and injuring or even killing men and animals.

Hoar-frost and *rime* are forms of frozen dew. Hoar-frost is deposited on bodies, such as stalks and leaves of plants, which radiate their heat away very readily.

CHAPTER IV.

GLACIERS.

In the last chapter we saw that the two chief agents in removing the excess of snow from a snow-field, apart from evaporation and melting, are glaciers and avalanches. The first of these is by far the more important. In the higher regions of a snow-field, the snow on the surface is loose and open in tissue, but in the deeper layers much of the imprisoned air is squeezed out by the pressure, and the snow is firmer and more compacted. On mountain slopes, and at the heads of valleys, the snow gradually acquires a slow, gliding movement; this further enables the air to escape, and the snow passes into a firm, granular condition, known as *névé* or *firn*. Where the slope is gentle, the *névé* may extend for miles with an almost unbroken surface, but as the descent becomes steeper, and the snow, confined within valleys, is pressed downwards from the sides as well as from behind, it gradually loses its granular, crystalline structure, and passes into clear blue compact ice, streaked, however, with white veins where the air has not been thoroughly expelled. The little tongue of ice which begins to steal down the valley is soon joined by other tributaries, until it swells into

FIG. 7.—FORMATION OF A GLACIER BY THE UNION OF TRIBUTARY ICE-STREAMS. SOME OF THE LATERAL MORAINES ARE COALESCING TO FORM MEDIAL MORAINES. —*Garwood.*

a great river of ice perhaps hundreds of feet thick and many miles long (Fig. 7.) A glacier such as this may extend a long distance below the snow-line before it is finally melted, terminating perhaps far down the valley in the neighbourhood of cornfields and orchards. The lower end of the Great Tasman glacier on the west coast of New Zealand is hidden by a grove of pines, beeches, and arborescent ferns.

Glaciers, though most abundant within the Arctic and Antarctic Circles, are by no means confined to Polar latitudes. In Europe, besides the ice-rivers of the Alps, glaciers occur in Norway, and in the ranges of the Pyrenees, and the Caucasus. In the vast chain of the Himalayas, the snowy peaks of which, in some instances, run up to 29,000 feet, glaciers of great size are formed, valleys even 60 miles in length being filled with continuous streams of ice. Glaciers are found in Africa on Mount Kenya and Mount Kilimanjaro, right under the Equator; they terminate now about 15,600 feet above the sea, but appear formerly to have had a much greater extension. In South America, glaciers occur in Tierra del Fuego in the extreme south, and at intervals northwards along the chain of the Andes, Chimborazo (20,500 feet), for instance, which is only 2° from the Equator, sending out glaciers in all directions. The glaciers of the Rocky Mountains are not of very great size, but further north, in Alaska, vast sheets of ice fill the valleys near the coast. The grandest

glaciers of the world are those which form on lands within the Polar regions. In Greenland, for instance, tongues of ice 2,000 or 3,000 feet in thickness and fifty or more miles in width steal down the valleys, and push their way far out into the sea, terminating by breaking up into icebergs.

A glacier has geological work to do of various kinds. Some of its effects are of a temporary nature produced by small advances or retreats of the ice and disappearing when the glacier resumes its normal condition; others are of a more lasting description, perhaps remaining long after all trace of the ice has vanished. The analogy of a glacier to a river extends even to many details. Just as a river is dependent for its existence upon the rainfall, and represents the drainage of a definite area of land, so a glacier is dependent upon the snowfall, and is the drainage channel of a snow-field. Like a river, a glacier wears away projecting masses of the rock over which it passes, and carries away loose material from the base and sides of its bed to be deposited at lower levels in the valley. A river moves faster in the centre than near the banks, and the water near the surface travels more quickly than that at the bottom; so also does the ice of a glacier move fastest in the centre and on the surface. At points in its channel where the slope of the underlying surface of the rock suddenly becomes steeper, a fall of ice occurs quite comparable with a waterfall.

A description, in greater detail, of a small glacier, such as those which exist among the Swiss Alps, will give us a clearer insight into the behaviour of these ice rivers.

A Swiss glacier, as a rule, in its lower part narrows down into a long tapering portion, which finally terminates in a rough slope of ice. From an arch in the base of this mass, issues a torrent of muddy water, especially large in summer, when much melting of the ice is taking place. The Frontispiece to this volume shows the termination of the Mer-de-Glace of Chamouni and the source of the Arveiron. On a sunny day numerous little rivulets are formed on the surface of the ice, and these uniting and finding their way down the crevasses help to swell the volume of the sub-glacial river.

Below the termination of the ice, the valley is everywhere strewn with earthy débris, blocks of stone, and boulders, often of a great size, brought down from the higher ground by the glacier. In places, these are piled into great heaps and ridges, generally of a roughly semi-circular shape, stretching across the valley and cut through by the glacial river. The accumulation of earthy rubbish and stones forms what is known as the *terminal moraine*. Some of the stones bear testimony to their passage under the ice in their smoothed, polished and striated surfaces and their sub-angular contours. Sometimes it happens that several ridges can be distinguished placed one within the other

across the valley. These indicate that the glacier was at one time larger than it is at present, but that since the outermost moraine was piled up it has been shrinking backwards, not continuously, but with pauses, each pause being marked by the formation of a moraine. In Switzerland some of the terminal moraines are many miles below the present limit of the ice, showing that the ancient glaciers were of immensely greater extent than their modern representatives.

Sometimes it is possible at the end of a glacier to creep in a little way beneath the ice, and so observe the striking effects which are produced upon the valley-floor by the passage of the ice along it. Everywhere the hard rocks are smoothed, and finely polished, and traversed by scratches ranging from the finest striæ to deep scores many feet in length, all roughly parallel and running in the direction in which the glacier moves. These scores and scratches are not produced so by the ice itself but by stones and rock-fragments firmly frozen into the bottom of the glacier. Dragged with resistless force over the surface of the rock, the stones themselves are ground down, polished and striated in the process. These effects may also be seen where a glacier has been shrinking, and has laid bare a part of its rocky channel. No other agent in nature can produce the appearances which characterise a valley that has once held a glacier. The smoothed, polished surfaces and the rounded contours

of the rocks tell their story with unerring certainty after the lapse of perhaps a vast interval of time.

On the top of the glacier, above the rough terminal face of the ice, stones, earth, and boulders are often so thickly scattered over the lower portion that the surface is completely hidden, and it is only by looking down a crevasse that the clear blue colour of the ice can be seen. Some of these blocks are poised right on the edge of the glacier, and are just about to roll down and add to the moraine below. Higher up the glacier, a region is reached where the ice is broader, and here the piles of earth and stones cease to be scattered irregularly over the surface, and begin to show traces of an orderly arrangement. Along each side of the glacier lies a heap of earthy rubbish gradually built up of masses of material which have fallen from the sides of the valley, while in the centre may be seen one or more ridges also running parallel with the length of the glacier. The accumulations at the sides are called *lateral moraines* (Fig. 8), those in the centre *medial moraines*. If a medial moraine be traced up the glacier to its point of origin, it will be found to arise from the coalescence of two lateral moraines at a point where a tributary of ice joins the main stream (see Fig. 7). At the lower end of the glacier, owing to movements of the ice, melting of the surface and other causes, these ridges lose their distinctness and are spread out over the whole surface.

Besides the lateral, medial, and terminal moraines, there is an accumulation of gravel,

Fig. 8.—Lateral and Medial Moraines on the Gorner Glacier.—*Garwood.*

stone and sand lying beneath the glaciers between the ice and the rock. This *ground moraine* or *moraine profonde*, as it is termed, is supplied by material derived from both the surface of the glacier and the bed of the valley. Boulders and gravel on the top are from time to time engulfed in deep crevasses, which extend from the surface to the bottom of the glacier, others slowly sink through the ice by reason of their own weight; at the same time constant abrasion is wearing down the rock-surfaces and grinding the fragments to powder underneath the ice, thus producing the fine mud with which the stream flowing from the end of the glacier is usually so thickly charged. The *moraine profonde* is constantly being swept away by the movements of the ice and the circulation of the sub-glacial water, and only accumulates to any considerable extent where the local conditions are favourable. Much difference of opinion exists as to the amount of material which is really transported in this way, some authorities holding that it is fairly large, while others consider that a large proportion is carried down actually embedded in the ice rather than beneath it. Observations made by Mr. E. J. Garwood on the glaciers of Spitzbergen support the latter view.

If one of the moraines on the surface of a glacier be examined it will, in general, be found that it is not composed solely of fragments of rock and earthy débris, but consists of a covering of these materials deposited round a

ridge of ice rising above the general level of the glacier. This results from the melting of the ice on the exposed parts of the glacier, while that beneath the moraine is protected from the sun, and ultimately, projects upwards as a ridge. The same sort of action is witnessed where a large isolated slab of rock has fallen upon the surface of the glacier. Gradually the ice which surrounds it is melted, and ultimately the boulder is left poised at the summit of a pillar of ice, its appearance now earning for it the title of *glacier table* (Fig. 9).

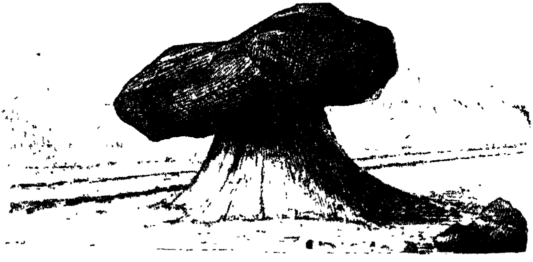

FIG. 9—A GLACIER TABLE.

As a rule, a glacier table is not set squarely upon its support, but inclines downwards in a direction and to a degree depending upon the latitude. In the Alps, for instance, it slopes from north to south; this is owing to the noonday sun being on the south of the zenith and melting the ice on that side, while the north side still remains in shadow. As the surface of the ice sinks, the pillar, exposed on all

sides to the air, gradually melts away, until eventually it becomes too thin to support its burden, which then falls over on to the ice, to be raised again, perhaps several times, in the course of its journey down the glacier.

When, from some cause, such as a diminished snowfall or a rise in temperature, a glacier is retreating, it leaves behind besides moraines isolated blocks of stone which indicate its former extent. These *erratics* have sometimes been carried many miles from their original positions; in Switzerland, blocks of stone, which could only have been derived from the higher parts of the Alps, have been found stranded far up on the slopes of the Jura Mountains. Some of these boulders are of immense size; one near Neuchâtel has been estimated to weigh 3,000 tons, and to contain from 40,000 to 45,000 cubic feet of material. Sometimes erratics are left poised in such precarious positions that apparently the slightest push would be sufficient to roll them over. These are termed perched blocks. Often they stand out on the tops of hills and ridges as prominent objects against the sky-line.

Besides the direct erosive action of the glacier, another effect is produced on the valley-floor in the bringing about of which running water plays a conspicuous part. During a summer day, an immense quantity of ice is melted on the surface of a glacier, and the water collecting into little runnels, which unite to form larger streams, flows over the ice, until

it falls as a rushing torrent down some crevasse. The continual beating of the stones and gravel swept down from the surface by the current, against a particular spot on the valley-floor, ultimately hollows out a hole, which may attain a considerable depth if the process be long continued. When, owing to shrinkage of the glacier, or movements in the position of the crevasse, the water is diverted to another channel, the cavity becomes filled up with mud and detrital material more or less rounded and polished. A section through it would then present the appearance shown in Fig. 23. Such cavities, known as "potholes," "cauldrons," or "giants' kettles," have frequently been found in valleys which formerly contained glaciers. A particularly fine group was discovered near the Lion Monument at Lucerne, the largest being about 26 feet wide and 28 feet deep. Several of them still retain the spiral form which the gyratory movement of the torrent impressed upon them.

As a glacier moves down over an uneven valley-floor, it often happens that portions of the lower layers become jammed, while the higher layers glide over them; or, perhaps, the nature of the ground will only allow the lower part to move obliquely, while the main mass preserves its original direction. Such movements give the ice a remarkably beautiful banded and plicated structure. Another effect of the glacier movements is seen in the formation of crevasses. When first formed,

these are mere cracks in the ice, not sufficiently wide to allow of the entry of a knife-blade, though they may often be traced for long distances to the right and left. Gradually, however, the walls move apart until they enclose between them a yawning chasm, extending from the top to the lowest depths of the glacier. On the edges of the crevasses, a coping of snow collects from which hang icicles many feet in length. This hardened snow, concealing, as it does, the true extent of the fissure is a source of great danger to the mountaineer, and is still more so, when, as sometimes happens, the two projecting masses unite, and thus completely conceal the chasm. A crevasse being formed in order to relieve the strain produced by a pull on the ice, it follows that the fracture takes place along a line at right angles to the direction in which the pull is exerted. Whenever, for instance, an increase in the steepness of the slope of the valley occurs, the glacier breaks it back, so to speak, a fissure being formed transversely across its centre. On the field of the névé, at the head of the glacier, crevasses are less frequent, but there is generally one, very constant in position, which separates the snow and ice of the glacier from that portion of the névé which is firmly frozen to the peaks above. This is known as the *bergschrund*. At the sides of the glacier the crevasses do not run transversely, but, in consequence of the strain set up by the more rapid motion of the centre, they slope obliquely upwards.

Often the transverse fissures of the centre unite with those of the sides forming great curved crevasses, which stretch right across the glacier, the convexity of the curve being turned towards the head of the valley.

In those places where an abrupt fall of the glacier-bed takes place, the number of crevasses becomes so great that the ice is completely scattered. Great transverse fissures split the glacier up into ridges, and these are again broken across into pinnacles and towers of ice, some of them of the most fantastic shape. This scene of confusion is an *icefall* (Fig. 10), and it is formed at a point where, if a river occupied the valley, a waterfall or a rapid would exist. At the bottom of the declivity, the broken fragments of ice soon become welded together again, and the glacier pursues its course as before. The formation of crevasses being then largely dependent upon the nature of the ground over which the glacier moves, we see how it is that a fissure may remain in one place, though the ice in which it occurs is constantly moving onwards. As fast as the crevasse is carried away from the point where it originated, it begins to close up, and a new one is opened behind it. This explains how it is a torrent of water can fall for so long a time upon the same spot of the glacier floor as to beat out the "giants' kettles" described above. A melancholy proof of the persistency of a crevasse was afforded by an accident which occurred on Mont Blanc. In 1820,

three guides were swept by an avalanche into a great chasm at the head of a snow-field called the Grand Plateau, at the foot of

FIG. 10.—"ICE-FALL" ON THE RHONE GLACIER.—*Garwood.*

the final slope up to the summit. More than forty years later their remains were found near the end of the Glacier des Bossons, many

miles below the point where they disappeared. To-day a crevasse still exists at the head of the Grand Plateau scarcely distinguishable from that which engulfed the guides nearly eighty years ago.

Considerable variations in the length and thickness of a glacier may be observed even within the space of a few years. At one time, the terminal face of ice may be observed to be slowly advancing, turning up the ground in front of it like a ploughshare, and clearing aways huts and châlets in its path ; at another time, it may slowly retreat leaving a large area of its bed exposed. These oscillations are due to slight variations in the temperature and in the amount of the snowfall. Between 1818 and 1842, the glacier of La Brenva, on the Italian side of Mont Blanc, shrank to such an extent that in some places its surface had subsided 300 feet. Previous to 1856, the glaciers of the Alps, with some local exceptions, appear to have been advancing, but about that date a general retreat commenced, which seems only recently to have ceased. Between the years 1854 and 1865, the glacier of Tour shrank back some 560 yards, and the Glacier des Bossons 350 yards. The glaciers in the Pyrenees and the Caucasus have also been diminishing since the middle of the century. The Muir Glacier in Alaska is said to have decreased in length by as much as half a mile between 1866 and 1890. In Spitzbergen, however, the glaciers appear to be advancing.

During a temporary advance it sometimes

FIG. 11.—THE ICE-BARRIER OF THE MARJELEN SEE.
Garwood.

happens that a glacier moves past the end of a tributary valley, and dams back the stream which is flowing down it. The water accumulates behind the ice, forming a lake, which continues to increase in size until the barrier, no longer able to resist the pressure, bursts, and allows the whole mass to rush headlong down the valley. Great destruction is then wrought by the flood, crops are devastated, and trees, cattle, and villages are swept away by the resistless rush of the water. Such a lake was formed in 1818, in the valley of the Dranse in Switzerland. An ice-barrier half a mile long, with a height of 400 feet and a breadth of 600 stretched across the valley, and held up a quantity of water, estimated at 800,000,000 cubic feet. The danger was recognised, and efforts were made to avert it by driving a tunnel through the ice; by this means, much of the water was drawn off, but, before the lake was completely emptied, the barrier gave way, and great damage was done to plantations in the valley below.

But glacier lakes are not all of this temporary nature. Sometimes the mouth of a lateral valley is closed by ice, and the water rises until it finds an exit over a neighbouring coll. Such a lake may remain until the glacier has almost disappeared, or at least, until a marked change of conditions has brought about a substantial reduction in its size. The beautiful Märjelen See (Fig. 11) on the Great Aletsch Glacier furnishes an

FIG, 12.—VIEW OF THE TERRACE WHICH IS FORMING AT THE EDGE OF THE MARJELEN SEE.—*Garwood.*

instance of a lake of this sort. From time to time, masses of ice are broken off from the cliffs against which the water laps, and float on the surface as small icebergs. On the rock-bound sides of the lake, stones and boulders dislodged from their positions are arrested when they reach the water, and tend to accumulate as a ridge or terrace along the margin (Fig. 12). The breaking of a barrier as the glacier shrinks back may lower the level of such a lake to a certain point, and then a pause may occur, during which a new terrace is accumulated. If this process is repeated more than once, each pause is indicated by the growth of a marginal ridge of stones and rock-fragments. In a later chapter we shall see that the famous "Parallel Roads" of Glen Roy owe their origin to action of this sort.

A good many references have been made to the motion a glacier exhibits, but it is still desirable to give some account of the rate of this movement and the manner in which it takes place. The gliding of a glacier down its valley is in direct obedience to the force of gravity, but it is rendered possible by the melting of the ice at those points where the pressure is greatest. The hard brittle ice thus behaves just like a viscous substance, such as pitch or resin, and is able to squeeze through narrow valleys, and make its way over rough, uneven surfaces. The shearing of the central portion past the layers of ice at the bottom and sides of the glacier, is due to

the friction these latter experience against the rough surfaces of the valley. The rates of movement of glaciers vary within considerable limits, but, as a rule, in countries outside the Polar Circles, do not exceed a few inches a day. Mark Twain, in the humourous account of his travels in Switzerland, describes how, after reaching the summit of the Riffelberg, he determined to make the descent by sitting on the glacier and allowing it to carry him down to Zermatt. Even if his glacier had moved at the greatest rate which has yet been observed in the Alps, it would still have taken him several years to have performed the journey. On the Mer-de-Glace of Chamouni the movement of the centre, in summer, is from 20 to 27 inches a day, and of the sides, from 13 to 19 inches. In the fiord of Torsukatak, in Greenland, where the ice is nearly five miles wide, the rate of movement is 24 feet daily; in that of Karajat, the ice travels 30 feet in a day. Even greater rates have been observed, the glacier of Jacobshavn moving at the rate of from 48 to 64 feet in the 24 hours. In winter the motion of a glacier is much reduced; on the Mer-de-Glace, near Montanvert, the rate is only about half what it is in summer.

Measurements of the rate of motion of a glacier are made by observing the position of an object on the ice before and after the lapse of a known interval of time. In 1827, a Swiss Professor, Hugi, built a hut upon the glacier from which the river Don issues, in order to

make scientific observations. In three years, the hut had moved 330 feet downwards; in 1836, it was some 2,000 feet lower; and in 1841, when Agassiz observed it, the total distance travelled from the original position was 4,712 feet. For more rapid measurements an instrument called a theodolite is employed. The essential part of this is a telescope, across the field of which are fixed two threads of spider web at right angles to each other. The theodolite is firmly fixed to a rock on one side of the valley, and the telescope is adjusted until the intersection of the threads coincides with some definite fixed landmark, such as a tree or a point of rock, on the opposite slope. An observer now takes his station at the telescope, and by means of signals, directs another who drives a row of stakes into the ice, right across the glacier, in the line between the telescope and the fixed point. After the lapse of 24 hours, or a longer period, the stakes are all seen to have moved downwards, so as to form a great curve across the surface of the glacier, but by means of the theodolite, the original positions are easily re-determined. The distance that each stake has moved during the interval can then be directly measured along the ice.

Most of the earlier investigations into the manner of formation and the behaviour of glaciers were conducted among the mountains of Switzerland; but during recent years, geologists have gone further afield, and on the great glaciers of the Polar regions have

observed many interesting features, which are not brought out by the smaller ice-streams in the mountain hollows of more southerly latitudes. The observations of Mr. I. C. Russell, of the United States Geological Survey, on the Malaspina glacier, in Alaska, and of Mr. E. J. Garwood and Dr. J. W. Gregory, in Spitzbergen, have in particular thrown light on certain problems connected with the glaciers of the past.

The Malaspina Glacier is a vast, nearly horizontal sheet of ice lying at the base of Mount St. Elias on the south-west shores of Alaska, and covering an area some 1,500 square miles in extent. The average elevation of the surface above sea level is about 1,500 feet. Several larger glaciers which come down from the mountains lying further inland, unite to form this great lake of ice, which has a termination over 70 miles in width, and an average breadth between the margin and the highlands of from 20 to 25 miles. In one place the glacier extends right out into the sea, where it terminates by breaking up into large masses which float away as icebergs. "The central portion is free from moraines and dirt, but is rough, and broken by thousands and tens of thousands of small crevasses. Its surface is broadly undulating, and recalls the appearance of portions of the rolling prairie lands west of the Mississippi. It is in fact a dreary and lifeless prairie of ice. From the higher swells of its surface one may see for miles in all directions with-

out observing a single object to break the even monotony of the broken ice-plain. On looking down on the glacier from an elevation of 2,000 to 3,000 feet on the hills bordering it on the north, even on the wonderfully clear days that follow storms, its limits are beyond the reach of vision. From any commanding station overlooking the Malaspina glacier, as from the summit of the Chaix Hills, for example, one sees that the great central area of clear, white ice is bordered on the south by a broad, dark band formed of boulders, and stones."* As with the Swiss glaciers, the ice is formed of blue and white bands. Observations show that the glacier has been retreating for a very considerable period.

The moraines, which form a great belt around the southern border of the glacier, are in places covered with dense forest growth, consisting chiefly of spruce, cottonwood tree, alder, small shrubs, bushes, and rank ferns. In some parts the vegetation extends over the moraine-covered area of the glacier itself, perhaps growing above ice more than a thousand feet thick. So dense was the growth that the exploring party could only cut their way through it with great difficulty. An extension of the glacier would overwhelm the forest growth with moraine material, and we should then have a deposit of soil and vegetation sandwiched in between two layers of

* I. C. Russell, *Am. Jour. Sci.*, 1892, p. 175.

glacial débris. In a later chapter we shall see that such a series has been taken as indicating more marked changes of climate than the above facts would seem to justify.

On the surface of the glacier, many features produced by the rapid melting of the ice may be observed. Glacier tables are numerous and also sand cones, which are formed by an analogous process. A mass of sand falls on to the glacier, and protects the ice beneath it from melting. It, in consequence, begins to be raised above the general level, but during the process the sand slips back, and thus a conical mound is formed. On the surface of the ice round the border of the glacier are many thousands of small lakelets.

The Malaspina Glacier is gradually melting away and it, in consequence, illustrates certain kinds of action, which appear to be peculiar to ice-sheets in this state of "stagnation." The drainage of the glacier is almost entirely, either through the ice or beneath it, only a few streams flowing over the surface, and those usually soon disappearing down a crevasse. On the north side of the glacier, the streams flowing from the mountains disappear through tunnels in the ice. On the south, they emerge all along the border still thickly charged with earth and stones. Some of the material swept along by the stream is deposited in the tunnel, but most of it is laid down where the stream leaves the glacier, gradually building a fan-shaped accumulation known as an alluvial cone. This piling up of

material at the end of the tunnel gradually tends to close the latter. The stream is consequently obliged to flow at successively higher and higher levels. Thus more material is deposited on the floor, and the roof of the tunnel is worn by the water. This process goes on until ultimately the ridge of stones and gravel reaches the surface of the glacier. Further melting at the sides causes some of the material to roll down from the top, forming a slope, and giving the ridge a kind of arched structure.

In a later chapter we shall see that certain glacial accumulations, known as asar, correspond very closely in character with the ridges forming on the Malaspina glacier, and were, in all probability, produced by a similar process.

Mr. E. J. Garwood and Dr. J. W. Gregory, who were with Sir Martin Conway's expedition in Spitzbergen in 1895 and the former again in 1896, made many valuable observations upon Arctic glaciers.

In most respects the glaciers of Spitzbergen agree with those of Switzerland; but an important difference is exhibited by many in the character of the terminal front, which, instead of gradually tapering off, ends in a vertical cliff of ice often overhanging at the top, in consequence of the more rapid movement forward of the surface layers of ice (Figs. 13 & 14). This was formerly considered to be due to the low angle under which the rays of the

sun in Arctic latitudes fall upon the ice. Glaciers of this type appear always to be advancing; those which narrow down into blunted points are either stationary or receding. The lower layers of these glaciers were generally so abundantly charged with débris that in places the explorers found it "impossible to draw any sharp line of separation between the glacier and the bed on which it rests." The process by which

FIG. 13.—TEMINATION OF BOOMING GLACIER, SPITZBERGEN.—*Garwood.*

intra-glacial material is picked up from the valley-floor and raised through the glacier was explained by the above-mentioned observers as follows:—"In a glacier which ends with a cliff-like face, the upper layers ride forward over those below, until they overhang as a projecting cornice. As the cornice is pushed still further forward, masses of it break away

and fall to the foot of the cliff. There they accumulate as an ice-talus bank, which in time becomes so large as to check the advance of the lower layers of the glacier. If the talus-bank is too heavy to be pushed forward, the glacier is forced to ride over it (Fig. 14). The ice, therefore, that was originally the uppermost layer of the glacier will then form the base, and be in turn forced to rise upward over later talus-banks that accumulate in front of it. . . . . When this basal layer of ice works upward, it carries with it the material which it has picked up from the valley-floor." In one instance proof of this was afforded by the nature of the material raised. Scattered through the lower layers and on the terminal moraine of Ivory glacier were numerous shells, fragments of whalebone and drift-wood, which could only have come from a lowel level. One fragment was found at a height of 400 feet.

The great importance of these observations is realised when we consider what would be the conditions if the glaciers disappeared. The shells and whalebone would then be left stranded, in some cases high up on the sides of the valleys, and might easily be regarded as evidence of a former submergence of the country beneath the sea. We shall see later that a great controversy has been waged over the mode of formation of certain shell-bearing deposits found on the mountain sides in various parts of Great Britain; some authorities considering that they are the records of

FIG. 14.—TERMINATION OF BOOMING GLACIER, SPITZBERGEN. THE UPPER LAYERS ARE RIDING OVER THE HEAP OF BROKEN MASSES OF ICE FORMED IN FRONT OF THE GLACIER.—*Garwood.*

a general submergence; while others hold that they were left by the retreating glaciers, being carried up, either upon the surface or through the ice, by some such process as that described above.

CHAPTER V.

ICE-SHEETS.

In many of the lands within the Arctic and Antarctic circles not only are the valleys filled with large glaciers, but the snow and ice override the barriers between, and swathe the whole country in an icy mantle, above which only the tops of the highest mountains project. To these cold and desolate expanses the term *ice-sheet* has been applied.

The largest ice-sheet in the Northern Hemisphere is that which covers the greater portion of Greenland. Its length is about 1,500 miles, and its average width about 400 miles, so that the area over which it is spread is considerably more than half a million square miles. Descriptions of the more accessible strip of coast land which surrounds this frozen mass were long ago brought back by navigators, indeed it was visited by the hardy Norsemen, who gave the country its name, as early as the tenth and eleventh centuries; but it was not until comparatively recent years that any accurate knowledge of the interior was gained. In 1878, Lieutenant Jensen succeeded in getting as far as a group of mountain summits which have since borne his name, situated about twenty miles from the nearest edge of the ice-sheet. Baron Norden-

skiöld, in 1883, starting from the west coast advanced due east for eighteen days, traversing in that time nearly eighty miles, but was obliged to turn back on account of the bad condition of the surface of the snow; two Laplanders, who were with him, went on for another forty or fifty miles. The next important expedition was made by Lieutenant Peary who, in 1886, going eastwards from Disco Bay reached a point 100 miles from the edge of the ice, at an altitude of 7,500 feet. The first complete crossing of the ice-sheet from coast to coast was made by Dr. Fridjof Nansen with five companions in August and September, 1888. Starting from the east coast, at about latitude 64°, the party travelled nearly 300 miles over a huge, gently-sloping plateau of frozen snow, rising to 9,000 feet in the highest part, and finally came down near Godthaab on the west coast. In 1892, Peary accomplished an even more daring and remarkable journey over the ice-sheet. Leaving Inglefield Gulf, near latitude 78° on May 3rd he reached the west coast on July 4th, at a point which was named Independence Bay, from the date of its discovery. Including the return journey a distance of some 1,300 miles of ice was traversed with the aid of sledges. Besides being some 1,100 miles further north, this undertaking was rendered more formidable than Nansen's traverse by the fact that, while the latter traveller was leaving the inhospitable shores of Eastern Greenland, and

at every step was approaching the abodes of men, Peary was during his outward journey continually increasing his distance from his base, and well knew that every advance had to be retraced. In 1895, Peary again traversed the northern ice-sheet along nearly the same lines as on the previous occasion. During these two crossings and three shorter expeditions Peary practically completed the determination of the northern outline of Greenland.

Of the configuration of the buried land-surface in the interior of Greenland nothing can with certainty be told, every ridge and hill-top being concealed beneath the shield of ice and snow. But judging from the boldness of the coast line, and the rapidity with which the land rises from the water's edge to a height of from two to four thousand feet, it is probably of a wild and mountainous character. Beyond the fringing strip of land the ice slopes gently up to an undulating plateau, rising in the highest parts to a height of 9,000 feet. The surface of this consists of frozen snow and in the interior, where Nansen crossed, it was practically free from crevasses or rivers. The snow, which falls sometimes for days together, takes the form of minute needles of ice, and this fine powder, when caught by the wind during a storm, is whirled over the frozen surface in blinding clouds, like sand in the Sahara. The cold in these regions is intense even in summer. On the nights of the 12th and 14th September Nansen

experienced a temperature probably as low as 45° C., or expressing it on the Farenheit scale, 113 degrees of frost; while the mean temperature of the days from September 11th to 16th, during which time they were about the centre of the ice-sheet, varied from 30° C. to 34° C.

The absolute purity of the inland ice was remarked by Nansen. When once beyond the last pile of débris derived from the mountains on the east coast, not a solitary stone or boulder was seen spotting the white unbroken surface of the frozen snow, until the main mass of the ice-sheet was traversed, and the western shores were neared. Moraines were of necessity absent, for there were no mountains to supply the material.

The observations made by Nordenskiöld on the eastern portion of the ice-sheet show that the ice in this region differs in some respects from that which Nansen crossed. No traces of moraine material were detected, but as far as he went—a distance of nearly eighty miles from the edge of the ice-sheet—a fine grey powder was found scattered over the surface of the ice. Analyses show that this dust is blown inwards from the mountains on the coast. Owing to the readiness with which it absorbs the heat of the sun's rays, little tracts of the powder tend to melt the snow beneath, and thus bring about the formation of holes sometimes two or three feet deep. Nordenskiöld found his progress much impeded by these cavities which, in some places, quite honeycombed the surface of the hardened snow.

Many rivers were met with flowing over the ice, and in places small lakes had accumulated, but during the return journey the thermometer fell to 11° C., and most of these were frozen. The abundant melting of the snow, in marked contrast to the severe conditions Nansen subsequently encountered nearly three hundred miles further south, was probably to be explained as the result of an unusually warm summer.

The coast of Greenland is of an extremely irregular character; like that of Norway, it is everywhere fringed with islets and broken into by numerous bays and fiords. Between the shore line and the ice-sheet runs a belt of mountainous country, down the valleys of which glide huge glaciers sometimes terminating in perpendicular walls of ice far out at sea. On the west coast this strip has an average width of 50 miles, and forms the home of some thousands of Eskimos. On the Atlantic border the coast land is far narrower, and the conditions too severe for the preservation of any forms of life. Stern and forbidding cliffs arise from the sea shore, and at the foot of these are great talus heaps formed by the accumulation of material split off by the intense frosts of winter. The freezing of the sea-water, and the stranding of floes and icebergs form a continuous ledge of ice along the beach, which renders any attempt at landing extremely difficult and dangerous.

The fringe of coast land does not plunge abruptly under the ice-sheet in the interior,

but becomes gradually overwhelmed as the snowfields increase and coalesce. The summits of the higher mountains can be seen breaking through the snow for long distances inland before they are finally covered. To these rugged peaks, which rise like islands in a sea of ice, Nordenskiöld gave the name "Nunataks" or "Nunatakka" (Fig. 15).

One of the best known groups of "Nunataks" is that which was explored by Jensen in latitude 63°. The surface of the ice in this region is about 4,500 feet above the sea-level, and the four principal peaks of the group rise up to heights ranging from 5,180 to 5,650 feet, so that about a thousand feet of each projects above the ice-sheet. Moraines stream out in various directions dependent upon movements of the ice, but none of them extend to any great distance, as the earth and stones of which they are composed are constantly being engulfed in crevasses. The longest dies out after a distance of about two and a half miles.

At some places near the margin of the inland ice, accumulations of rock and stones have been observed, which cannot be explained as the débris derived from any adjacent "Nunatak." Such a ridge, 500 feet high and over two miles in length, was described by the Jensen expedition. Although this consisted of a central core of ice, with only a superficial layer of earth and stones, still the material was too abundant to have been supplied by any of the mountain summits in the neighbourhood.

FIG. 15.—" NUNATAKS."—*Garwood.*

The rounded and polished character of many of the stones showed that they had been brought from a distance, and had travelled beneath the ice rather than upon it, being subsequently raised to the surface by internal movements in the mass. The manner in which material is thus raised from a low to a higher level in the ice has not yet been satisfactorily explained.

The glaciers of Greenland, which drain the great inland ice-sheet, exhibit in general the same features as those of Alaska and Spitzbergen. Some of them are of huge size. The great Humboldt Glacier, which enters Kane Basin on the north-west coast, has a terminal front upwards of sixty miles in extent. Those glaciers which push their way into the sea (Fig. 16) usually terminate in vertical walls of ice sometimes hundreds of feet in height, from the faces of which great masses are constantly breaking off and floating away as icebergs, perhaps to drift immense distances before finally melting (Fig. 16). The behaviour and distribution of icebergs will be more fully considered in a later chapter. Except for marginal accumulations, the surfaces of the glaciers are generally quite pure and spotless, and the icebergs carry away little or no earthy material, save perhaps a few stones frozen into their under surfaces. But those masses which break away from the extreme edge of the glacier are not unlikely to be strewn with earth and stones.

Other ice-sheets occur in the Northern

FIG. 16.—VIEW OF AN ARCTIC GLACIER, COMING DOWN TO THE SEA AND BREAKING UP INTO ICEBERGS.—*Garwood.*

Hemisphere, notably in Spitzbergen, Franz Josef Land, and the New Siberian Isles, but none of these attain the size or importance of that which covers Greenland.

In spite of their cold and cheerless character, the stretches of land adjoining the ice-sheets of the Polar regions are by no means so devoid of life as might at first be imagined. The power plants and animals possess, of adapting themselves to the conditions which surround them, nowhere meets with a finer illustration than in these inclement areas.

On the coast of Greenland little shrubs, grass, and even flowering plants, spring up in sheltered nooks among the rocks, and flourish during the short summer, while on the more exposed mountain sides are mosses and dull gray or orange-coloured lichens. In the ravines grow whole forests of the dwarf Arctic birch or willow, small stunted forms rarely attaining a greater height than two feet. One of the most conspicuous shrubs is the crowberry or curlew berry, the black, juicy fruit of which is largely eaten by the Eskimos in early autumn. Among the flowers are found daisies, buttercups, the little blossoms of the white-starred chickweed, dandelions, purple lychnis, cinquefoil and other brightly-coloured forms. Nansen speaks of the great delight with which he saw saxifrages, poppies, and stellarias growing in the crannies of the rocks when, at the end of his long tramp over the frozen sea, he reached the north coast of Franz Josef Land. Even on Jensen's

"Nunataks" many species of plants have been found. A very beautiful effect is sometimes produced by a small plant which lives and grows upon the surface of the snow, and imparts to it a delicate rose colour which may extend over a considerable area. *Sphærella nivalis*, as it is called, belongs to the group known as *algæ*, plants of very simple structure, generally flourishing in ponds and streams. Each individual plant is extremely small, but a large number of them growing together produces the effect which is known to Arctic explorers as "red snow."

The animal life of the Arctic regions includes only about eight or ten species of land mammals, though a few more such as the dog and the goat have been introduced by man. The reindeer, the most useful of these animals to man, is distributed over the northern parts of Europe, Asia, and America. In former years large herds existed in Greenland, but the more common use of the rifle for hunting them has greatly reduced their numbers. It is estimated that between the years 1845 and 1849 no less than 25,000 reindeer were annually killed. The Polar bear is found on the coasts, and is often met with right out on the frozen sea many miles from land. Two varieties of the Arctic fox exist, the blue and the white; the latter, during the summer months, is of a dirty greyish-brown colour, but in the winter it becomes pure white. Nansen saw trails of foxes in the snow as far north as the

85th parallel. The change of colour, according to the season, which is exhibited by the fox and certain other Arctic animals and birds, is one of the methods Nature adopts for the protection of life. The foxes are as inconspicuous against the dull grey rocks and lichens of summer as against the white snows of winter. Other animals found in Greenland are the ermine, the Arctic hare, and the musk ox, which appears to be confined to the extreme northern and eastern shores. Thousands of seals, walruses and whales inhabit the icy seas of the north. During the summer months the cliffs along all the coast-lines are the breeding places of swarms of seafowl; the air at times is filled with the screams of kittiwakes, gulls, fulmars and guillemots. Little auks occur in vast numbers. Ross's gull is a pretty form, not very frequently seen, with a delicate rose-coloured breast. As the sun sinks, and the long Polar night approaches, the birds gradually fly southwards to less inclement regions, returning to their old haunts in the following spring. Of land-birds not many species occur, but rock ptarmigan are abundant on the coast of Greenland, while Nordenskiöld's Laplanders saw ravens more than 80 miles from the edge of the ice-sheet. Nor is insect life absent; beetles, butterflies and moths are found, while at certain times mosquitoes are extraordinarily abundant. Nansen describes one remarkable experience as follows: "Whole clouds of these blood-thirsty demons swooped upon my

face and hands, the latter being at once covered with what might well have passed for rough woollen gloves. . . . We ran from one rock to another, hung our handkerchiefs before our faces, pulled down our caps over our necks and ears, struck out and beat the air like lunatics, and, in short, fought a most desperate encounter against these overwhelming odds, but all in vain."* It was only by taking to the boats that relief was obtained.

No account of life in the Arctic regions would be complete without some reference to that singular race of people the Eskimos. The largest settlement is in north-east Alaska, where about 20,000 of them live. From here they are scattered sparsely along the northern border of America and down the coast of Labrador. Western Greenland supports about 10,000, while a small colony exists on the Asiatic side of the Behring Straits. They are, of necessity, almost entirely meat-eaters, subsisting chiefly upon the flesh of reindeer and seals. The latter are often hunted on the sea in very light skin-covered canoes known as kayaks, in the use of which the Eskimos acquire, by long practice, a marvellous dexterity. The skins of the seals are chewed by the women until pliant, and are then used for making boots, covering canoes, and other purposes. Clothes are made of the skins of birds and of reindeer. In the south of Greenland the huts are built of stones

* "The First Crossing of Greenland," vol. I., p. 397.

and turf, but in the far north snow huts are made in winter, and abandoned for skin tents on the approach of warmer weather. In Danish Greenland the natives have all been converted to Christianity; and in Labrador the same results have attended the efforts of Moravian missionaries. The wise rule of the Danish Government has introduced into Western Greenland many of the advantages of civilization, while avoiding the evil effects which too often follow the intercourse of civilized with native races. The sale of alcohol is absolutely prohibited and that of tobacco much restricted; education is encouraged and nearly all the men and women can now read and write; a printing press has been set up at Godthaab, and a native post established.

The distribution of ice-sheets in the Northern Hemisphere presents many points of great interest. We are apt to imagine that the North Pole is the centre of the cold region, and that the temperature rises at an equal rate in every direction in proportion as we recede from it. The degree of cold at any locality is then judged by the degree of latitude. The use of the term "Arctic Circle," which is a perfectly arbitrary geographical line, rather tends to encourage this view than otherwise, many persons falling into the error of supposing that it marks the southern boundary of the snow and ice. As a matter of fact the distribution of snow and ice over the northern regions is extremely irregular; in some places the terminations of the ice-

sheets, or the margins of the frozen seas, extend far below the Arctic Circle, in others they lie many miles to the north of it.

A glance at a map of the north Polar regions will soon show how much the conditions vary among places situated at the same distance from the Pole. The greater part of Norway, for instance, lies between the same parallels of latitude as the southern half of Greenland; yet one is a fertile and populous country, nurturing glaciers only on the higher ground, while the other is chiefly a dreary waste of snow and ice. In this case, there is evidently a difference in the temperatures of the two countries; but in Northern Siberia the cold is as intense as in Greenland, yet no ice-sheet is formed and there is only a small amount of snow. These apparent anomalies must be examined more closely.

A low temperature is of course one of the first conditions which must exist for the formation of an ice-sheet. If there were no disturbing influences at work, places equidistant from the Poles would all have the same temperature, but owing to the existence of ocean-currents, winds, and other causes, a locality is often considerably warmer or colder than other places on the same parallel of latitude. Norway and Southern Greenland have already been compared, but the difference of temperature they exhibit extends further south. Dublin and the south-eastern headlands of Labrador lie on the same parallel of latitude, yet the mean annual temperature of

the former is 50° F., while that of the latter is as low as 32° F. London, in latitude 51·30°, has a yearly temperature of 50·8°, which is the same as that of Philadelphia, although the latter is situated nearly 800 miles nearer the Equator.

A very convenient method of mapping temperatures is by drawing lines between all the places which are known to possess the same temperature. Such lines when completed are called *isothermals*. In the Northern Hemisphere they run round the globe in great sweeping curves, sometimes dipping to the south, at others, bending northwards; in the Southern Hemisphere they are more regular. Let us, for instance, trace the isothermal of 32° F., that is to say, the line at any point of which the average temperature for the year is the freezing point of water. Starting near the south coast of Alaska, it at first runs gently southwards, and then straight across Canada, reaching the coast a little to the north of Newfoundland. Here the line takes a sudden bend northwards, touching the southern portion of Greenland, the north coast of Iceland, and then running right away upwards to beyond the seventieth parallel. After completely clearing the north coast of Norway it drops abruptly southwards as far as the Gulf of Bothnia. From the coast of the Pacific near Saghalien it slopes gently northwards into Alaska. At its most northerly position, north of Norway, this line is no less than 1,300 miles nearer the Pole

than it is at its most southerly points in Canada and Eastern Asia. The various influences which cause this line to deviate so much from the circle are too numerous and complex to be considered here; but we may point out that the abnormally warm temperature of Western Europe, which is indicated by the great northward bends of the isothermals in this region, is largely due to the great ocean-current flowing from warm Equatorial seas which has received the name of the Gulf Stream. On the other hand, the cold current which streams out from the Arctic Ocean down the coasts of Greenland, Labrador, and Newfoundland carrying great icebergs along with it, has effects of precisely the opposite character, still further increasing the difference of temperature between the eastern and western sea-boards of the Atlantic.

But this consideration of temperature does not remove all the difficulties connected with the distribution of ice-sheets. Turn again to the map, and look at the isothermals over the northern part of Siberia. It will be seen that a large strip of the country lies within the line of 5° F., that is to say, the mean annual temperature is equivalent to twenty-seven degrees of frost. Even in Yakutsk, as far south as latitude 62 deg., that is about the same distance from the Pole as the Faroe Islands, the January temperature is as low as 40° F., while the soil is frozen throughout the year to a depth of 700 feet, a little melting on the surface being all that the heat of the

summer can effect. Yet, in spite of the intense cold, ice-sheets and even glaciers are quite absent from this area. The reason of this is that Northern Siberia is swept by winds which are dry, no matter from what quarter they blow. Those which come down from the Polar Sea are too cold to contain much moisture, while the winds from the south, east, or west have passed over wide stretches of land, and have long since deposited their aqueous vapour in the form of rain or snow upon the flanks of mountain chains. The snowfall is in consequence extremely slight, and the snow never accumulates, even in winter, in sufficient amount to give rise to a glacier.

An important factor in determining the size and thickness of an ice-sheet is the area of the gathering-ground of the snow. The small islands round the coast of Greenland are generally only covered with a mantle of snow; even the larger ones to the north of the American Continent, though often supporting important glaciers, do not form ice-sheets.

Our knowledge of the ice-sheets, which form within the Antarctic Circle, is scanty in the extreme. The South Pole never seems to have possessed the same fascination for explorers as the North Pole, and far fewer expeditions have been sent out to investigate the regions which surround it. Another obstacle to Antarctic exploration is the extreme severity of the conditions which

prevail in high southern latitudes. The cold here is more intense than in the corresponding part of the Northern Hemisphere, and the ice-pack on the sea extends to much lower latitudes. Land has been seen at several points within the Antarctic Circle, and coasts have been followed for long distances, but, except in the case of a few islands, the barrier of ice has presented an insurmountable obstacle to landing. The highest latitude which has yet been attained in the Southern Hemisphere is 78° (equivalent to about 830 miles from the Pole) while in the Arctic Circle Nansen has succeeded in reaching latitude 86° 13.6′, a point only some 260 miles from the Pole.

The celebrated Captain Cook appears to have been the first explorer who passed the seventieth parallel, reaching latitude 71° 10′, longitude 106°, 54° 54′ W., in the year 1772. In speaking of the difficulties he encountered, he says :—" The risque one runs in exploring a coast in these unknown and icy seas is so very great that I can be bold enough to say that no man will ever venture further than I have done, and that the lands which lie to the south will never be explored. Thick fogs, snowstorms, intense cold, and every other thing that can render navigation dangerous, must be encountered, and these difficulties are greatly heightened by the inexpressibly horrid aspect of the country, a country doomed by nature never once to feel the warmth of the sun's rays, but to lie

buried in everlasting snow and ice. The ports which may be on the coast are, in a manner, wholly filled up with frozen snow of vast thickness; but if any should be so far open as to invite a ship into it, she would run a risque of being fixed there for ever, or of coming out in an ice island."

Since Captain Cook's discoveries two explorers have succeeded in getting further south. Weddell, in 1823, reached latitude 74°, but saw no land, and Sir James Ross, in 1841 and 1842, sailed as far as the 78th parallel. It is to the numerous and important observations made during the voyages of the latter that we owe the greater part of our knowledge of the regions which lie within the Antarctic Circle. The pack-ice of the sea was encountered as far north as lat. 67°, but more open water was found further south, and land was discovered in lat. 70°, to which the name Victoria Land was given. The coast was traced for about 500 miles southwards, but everywhere the shores were thickly covered with ice, which projected into the sea and terminated in a vertical cliff from 150 to 200 feet in height. "In a few places the rocks broke through their icy covering, by which alone we could be assured that land formed the nucleus of this, to appearance, enormous iceberg."* Nowhere was it possible to set foot on the mainland, but landings were effected on some of the more accessible

* Ross' Voyage of Discovery and Research in the Southern Antarctic regions, vol. i, chap. vii.

islands. Inland a range of lofty mountains could be discerned, their snow-clad peaks rising to elevations of from 7,000 to 10,000 feet above sea-level. Rather south of latitude 77° were two volcanic cones 12,400 and 11,000 feet in height which were named after the explorers' ships Mount Erebus and Mount Terror. The former of these was in active eruption at the time, and the pouring forth of the lava amid the eternal snows and ice presented a scene of grandeur rarely witnessed by man.

From evidence derived from soundings, from the nature of the rocks found on adjacent islands, or the glacier-borne stones dredged up from the seas in the vicinity, and from other indications it appears probable that a vast area of land caps the South Pole, not less than 4,000,000 square miles in extent, and thus worthy of being ranked as another continent. No trace of land-animals or vegetation has ever been found on any of the islands which have been reached within the Antarctic Circle, not even a solitary lichen or a piece of seaweed. The scanty flora of Cockburn Island appears to mark the southern limit of terrestrial vegetation, though marine forms extend somewhat further.

CHAPTER VI.

FLOATING ICE.

As far as this chapter we have been dealing with the phenomena exhibited by land-ice; that is ice, whether valley-glacier or extensive sheet, formed on land-areas by the gradual hardening of accumulated snow. But the ice which is found covering the surface of water presents many features of interest equally meriting our attention. In northern latitudes the rivers and lakes are more or less frozen over during the winter, while in the Polar regions the surface of the open sea is encumbered with ice throughout the year. It is convenient to deal with these two chief forms of floating ice separately.

The Ice of Rivers and Lakes.—In countries such as Canada and Siberia, where the winter frosts may be severe and prolonged, the rivers, lakes and canals are often frozen to a depth of from two to three feet. Ice palaces are built, heavily-laden waggons pass from side to side, and even railway lines have been laid down, and trains driven across the frozen surface. But even countries further south, which usually enjoy a mild winter, are from time to time visited by a spell of hard frost which produces unwonted scenes upon their rivers and lakes. In the year 401, and again in 642,

so intense was the cold in southern Europe that the Black Sea was completely covered with ice. The Thames was frozen over in 1063, 1434, and 1515. In 1594 the Rhine, the Scheldt, and even the sea at Venice were frozen. The Baltic has on several occasions been sufficiently encrusted to allow men and horses to traverse it, and in 1658, Charles X. of Sweden marched a whole army across the ice from Holstein to Denmark. The winter of 1684 was bitterly cold; in England, forest trees, even oaks, were split by the frost and many killed. Nearly all the birds perished. The Thames was covered with ice eleven inches thick and a citizen of the time records that "people kept trades on the Thames as in a fair till February 4th, 1684. About forty coaches daily plied on the Thames as on drye land." In 1691, the cold was so severe that wolves, driven by hunger, actually entered Vienna and attacked men and animals. Severe winters were experienced in 1740 and 1789; in 1814, oxen were roasted whole, and a great "Frost Fair" was held on the Thames.

The ice which is formed on the surface of rivers has geological work to perform of several kinds. Transport of material often takes place on a considerable scale. Stones and boulders lying on the beach become surrounded by a cake of ice, and when the general break up of the surface occurs on the approach of spring, they are floated away from their positions, and perhaps carried long

distances down the river before being dropped or stranded on the banks. Even animals are sometimes caught by the ice, and ultimately swept down stream. M. Huc saw a number of black objects in the ice on the Mouroni Ousson, a large river in Thibet, which on closer inspection proved to be the heads of fifty wild buffaloes. They had evidently attempted to swim across the river just when the ice was forming, and had been caught and frozen in. Only their great horns projected above the surface, though their bodies could be seen encased in the ice*.

Where the beach is shelving, the expansion of the ice during a rise of temperature carries loose earth and stones up the slope. This process is repeated at such rise and fall of temperature, until a ridge is formed along the margin of the river. If, during the breaking up of the ice, a storm arises, blocks of ice are driven up the beach, carrying stones and gravel with them, which remain when the ice melts, and add to the volume of the marginal accumulations. Thus an embankment of considerable size and length is built up. These "shorewalls," as they are called, are frequently found along the banks of the rivers in Canada. In some places much destruction is wrought by the drifting masses of ice at the close of winter; bridges and quays are damaged, bays excavated in the banks, and even entire islands swept away.

* "Voyage en Thibet," vol. ii, p. 219.

Such results are frequently seen on the St. Lawrence in Canada; Crab Island, for instance, which at the beginning of the century had an area of an acre and a half, has been completely destroyed by the repeated onslaughts of the ice.

Serious floods are sometimes produced by the bursting of barriers formed by the jamming of masses of ice between narrows and against banks. This kind of action is particularly well seen on the rivers of Russia and Siberia which flow from south to north. The ice in the higher and warmer parts of their courses is the first to break up, and the floating masses are drifted down the stream and piled up against the still frozen surface further north. Behind the ice a great volume of water accumulates until, when suddenly released by the bursting of the barrier, it rushes out with great violence, carrying destruction far and wide.

The Ice of the Sea.—In the Arctic and Antarctic regions the surface of the open sea is more or less covered with ice throughout the year; while fringing the shores in the bays and fiords of the land is a continuous belt of ice which attains great thickness in consequence of the rise and fall of the tide and the accumulation of snow upon it. This rampart is known as the *icefoot* (Fig. 17.)

In North Greenland the icefoot frequently has a breadth of 120 or 130 feet, and a height of 20 or 30 feet above the general level of the sea. In the far north it never completely

disappears, but further south it is broken up during the summer months, and large pieces are floated away which, mingling with the floe-ice on the sea and the icebergs derived from glaciers, help to swell the pack. During the winter immense quantities of loose

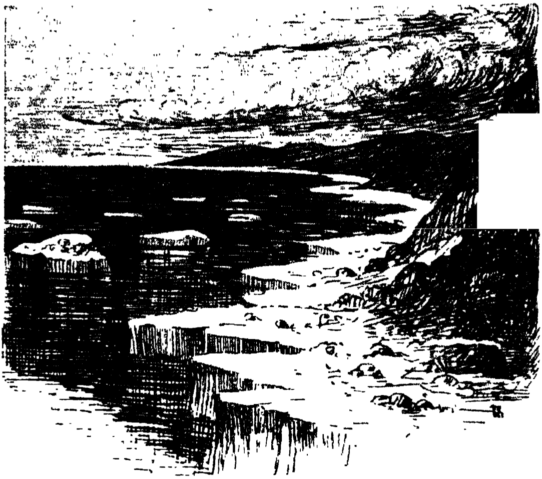

FIG. 17.—THE ICE-FOOT OF THE ARCTIC REGION.

material, split off from the cliffs by the frost, accumulate upon the icefoot, and at the breaking up of the ice are carried away to the south. In the under surfaces of the blocks are embedded stones derived from the beach.

During a gale masses of sea-ice are often

FIG. 18.—THE FROZEN POLAR OCEAN. NANSEN NEAR THE 86TH PARALLEL. (FROM "FARTHEST NORTH.")

driven on shore with tremendous violence, tearing up the beach in their progress, and glaciating the rocks over which they pass. Pebbles embedded in the under surfaces are scratched and polished on their exposed sides. It is of the highest importance to be able to distinguish the effects which are produced by shore-ice from those which result from the movement of a glacier. Sometimes the irregular nature of the scratches and their frequent change of direction enable one to refer them to the action of shore-ice; but in other cases no distinct difference can be observed. Mr. E. J. Garwood and Dr. J. W. Gregory, when in Spitzbergen, paid special attention to this point, but "saw no means of discriminating between the striæ produced respectively by glaciers and floating ice."

The open surface of the Polar Sea when undisturbed does not, as a rule, freeze to a greater depth than from six to eight feet; though in some places as, for instance, in the vicinity of Spitzbergen, the ice formed by direct freezing attains a thickness of over twenty feet. But owing to currents, tides and winds, the smooth sheet of ice is broken up into large flat pieces or *floes*, and by the piling of these one on another great irregular masses and hummocks are built up (Fig. 18). During a storm the floes are driven against each other with tremendous force; great blocks of ice are broken off and forced up on to the surface, and ridges are formed, often extending for miles. Interspersed with the

masses of marine ice, even long distances from land, are icebergs broken off from the terminations of glaciers. An observer on the ice-field appears to be standing in the middle of a wilderness of ice-ridges, sharp broken floes and rounded hummocks extending as far as eye can reach. In winter, the sheet of ice is more or less continuous, but even at this season "lanes" or channels of water open in it from time to time. In summer, the ice-field breaks up, and the disrupted floe ice constitutes what is known to navigators as the *ice-pack*. This is a source of great danger to whalers and other vessels. Many a stout ship has been caught in the pack and crushed by the ice-floes; others have been firmly frozen in and carried long distances before being freed. Portions of the ice-sheet may drift southwards, but they never reach such low latitudes as the vastly greater icebergs do.

The floe-ice, as a rule, is quite free from earthy material, though those pieces which have drifted from the neighbourhood of land sometimes carry a little earth or stones. Occasionally, however, it is of a brownish-red colour owing to the presence of large numbers of minute organisms, chiefly diatoms and other algæ. In the pools formed on the surface of the ice by the heat of the sun's rays in summer (Fig. 19) swarms of tiny animalcules exist, and Nansen even detected bacteria among them. Some of the floes furnish excellent examples of the

plasticity of ice. One, which Nansen saw, over three yards in thickness, had been bent into great waves by the pressure of the surrounding masses without breaking, the stratified character of the floe rendering the folding very conspicuous. At low temperatures the ice is hard and brittle, and the fractures, which occur during the winter packing, are accompanied by loud reports; but in the summer months, when near the melting point, the ice is tough and more plastic, while extensive chasms may be formed with comparatively little noise.

Much information concerning the currents which stream out from the Polar Ocean has been obtained from observations of the drift of floe-ice and of objects carried along with it. An accurate knowledge of these currents is of the highest importance, for upon them the success of Arctic expeditions often largely depends. On the west coast of Greenland a strong, ice-laden current sets down through Baffin Bay and Davis Straits and is joined off Cape Farewell by another cold current flowing along the east Greenland coast (Fig. 36). The united stream sweeps down the coasts of Labrador and Newfoundland, lowering the isothermals in this region, and carrying icebergs far into the Atlantic. Some remarkable instances of the drifting of ships, or the crews of shipwrecked vessels which have taken refuge on the ice-floe, have occurred in the Greenland currents.

On the 8th of May, 1854, Sir Edward

Belcher, while searching for traces of the ill-fated Franklin expedition, was compelled to abandon one of his ships, the *Resolute*, in Barrow Straits to the north-west of Baffin Land about latitude 75° N. and longtitude 95° W. Sixteen months later the *Resolute* was picked up by an American vessel off Cumberland Sound in latitude 67°, having drifted 1,100 miles during the interval. The *Fox*, the vessel in which Captain M'Clintock at last succeeded in reaching the spot where the records of Sir John Franklin were buried, was frozen into the ice pack from August, 1867, till the following April. During the 242 days which she drifted the *Fox* was carried southwards no less than 1,385 miles. Still more remarkable than these drifts was the experience of part of the crew of the *Polaris*, a vessel which sailed from Connecticut in the summer of 1871, with the object of exploring the regions to the north-west of Greenland. About the middle of September of the following year the ship was firmly frozen into the pack in latitude 79°, near the entrance to Smith Sound. On the 15th of October a storm arose, and the position of the ship became so precarious, in consequence of the presure of the floes which threatened to crush her at any moment, that a supply of provisions was hastily placed upon the ice, and some nineteen persons retreated thither. During the night a channel opened between the floe and the ship, and the two parties rapidly drifted apart. On the 18th the *Polaris* was

still in sight, but those on the ice were unable to reach her. Among the little party, which thus commenced a drift destined to last for nearly seven months, were two Eskimos with their wives and children, including a baby only a few weeks old, while their stores consisted of "two boats, some clothes-bags and musk-ox skins, fourteen cans of pemmican, fourteen hams, some canned meat, a small bag of chocolate, the tent built on the floe previously, and twelve bags of hard bread therein," these were supplemented by the occasional shooting of birds and seals, and in March a bear. Three snow huts were built on the ice-raft, and a fire was sometimes made by using the blubber of the seals as fuel. Great pieces of the floe broke off from time to time, but though constantly diminishing in size the portion of the ice which bore the encampment remained intact. On April 1st they took to their boats, but were soon driven by a gale to again seek refuge on the ice. Finally they were picked up by the steamer *Tigress*, on April 30th, in latitude 53° 35′ N. The party had been 197 days on the ice and had traversed a distance of 1,700 miles during that time; but in spite of the hardships and privations they had endured not a single life had been lost.

The drifts of the *Resolute*, the *Fox*, and the crew of the *Polaris* were in the West Greenland current, but a no less striking instance occurred in the great current which flows down the eastern coast. The *Hansa*, a

brig, which left Bremen in June, 1869, was crushed in the ice off the east coast of Greenland in about latitude 71° N. The crew escaped on to the floe, and here they passed Christmas in a house built of patent fuel. In two months they had been carried south 400 miles; and by the end of May they had drifted 1,100 miles on the ice raft. In June, 1870, they succeeded in reaching the Moravian Mission Station of Friedriksthal, west of Cape Farewell.

Besides the East and West Greenland currents there is another great ocean stream which flows from the north of Behring Strait and the coast of Siberia right across the regions round the Pole and out into the Atlantic. The deduction of the existence of this current from the physical nature of the Polar basin, and from the scanty evidence supplied by drifted objects, together with its actual verification by means of an expedition, form one of the most fascinating chapters in the history of Arctic exploration.

In July, 1879, a steamer, the *Jeannette*, left San Francisco with the object of attaining the Arctic regions by means of Behring Strait. After being beset in the pack for twenty-two months, the vessel was crushed by the ice in June, 1881, and sunk in latitude 77° 15′ N., longitude 155° E., north of the New Siberian Isles. The officers and men dragged their boats over the ice, and eventually reached one of the islands from which, on September 12th, they set out in

three boats for the mouth of the Lena; but only one crew succeeded in reaching Irkutsk with the melancholy tidings. In 1884, three years after she foundered, some articles belonging to the *Jeannette* were picked up by the Eskimos on the east coast of Greenland and handed over to the Colonial Manager at Julianshaab. These articles, which comprised a list of provisions signed by De Long, the commander of the *Jeannette*, a list of the boats, and some portions of clothing marked with the names of members of the crew, must have been carried by the drift right across the Pole.

These facts came under notice of Dr. Nansen, who soon obtained further evidence pointing to the existence of a great ocean-current flowing across the Polar Sea. Fragments of drift-wood were found on the coast of Greenland, much of which could only have been derived from Siberia; the mud on some of the ice-floes, when analysed, was found to contain the same constituents as that which forms at the mouths of the Siberian rivers, even the diatoms in it belonged to the same species. Still more convincing was the discovery of a "throwing-stick," a weapon for hurling bird-darts, like that employed by the Eskimos of Alaska, even to the ornamentation with Chinese glass beads, but totally dissimilar from anything used by the Greenlanders.

The existence of such a current can also be inferred, as Nansen pointed out, from the

magnitude of the current which passes between Spitzbergen and Greenland. "If we . . . consider what an enormous mass of water it carries along, it must seem self-evident that this cannot come from a circumscribed and small basin, but must needs be gathered from distant sources. . . . It is probable that the Polar current stretches its suckers, as it were to the coast of Siberia and Behring Strait and draws its supplies from these distant regions." * Moreover, the geographical relations of the land and sea round the Pole furnish an argument for the trans-polar current. The Arctic Ocean is largely a land-locked basin, into which great volumes of water are carried, through Behring Strait, and by the Gulf Stream, while numerous rivers of Northern Europe, Asia and America pour into it the rainfall of a vast area of land. "It thus becomes inevitable, according to the law of equilibrium, that these masses of water should seek such an outlet as we find in the Greenland polar current." *

Convinced of the existence of the current, Nansen formed the daring plan of exploring the Polar regions by allowing a ship to become frozen into the ice off the north coast of Siberia. If the theory was correct, she should drift across or near the Pole, and come out into the Atlantic somewhere between Greenland and Spitzbergen. The plan was put into operation, and the complete success

* "Nansen's Farthest North," vol. i. p. 24.

which attended it has been told in the two volumes of "Farthest North." The *Fram*, a vessel built of such a form as to be lifted on to the surface rather than crushed by the ice, left Norway on the 21st July, 1893, with Nansen and twelve others on board, and in September of the same year, was frozen into the ice-pack to the west of the New Siberian Islands (Fig. 19.) For nearly three years she drifted across the frozen ocean, getting during that time, well beyond the eighty-fifth parallel, a higher latitude than any vessel had ever previously reached, and at length broke free from the ice in August, 1896, to the north-west of Spitzbergen. Norway was reached on August the 20th. Thus Nansen's theory of the drifting of the ice from the coast of Siberia across the Polar Sea and out into the Atlantic was placed beyond doubt.

Nansen himself did not return with the *Fram*. In company with Lieutenant Johansen, he left the ship on the 14th of March, 1895, in latitude 84° 4′ N., and longitude 102° E. Their equipment consisted of three sledges drawn by twenty-eight dogs, on which were placed two kayaks as well as instruments, ammunition and provisions. For twenty-two days the intrepid explorers pressed on towards the Pole, reaching on the 8th of April latitude 86° 13·6′ N., the most northerly point ever attained by man. Here the surface of the ice became so bad that further progress was impossible; on all sides was "a veritable chaos of ice-blocks stretching as

far as the horizon." Turning southwards they made for Cape Fligely, and, after an

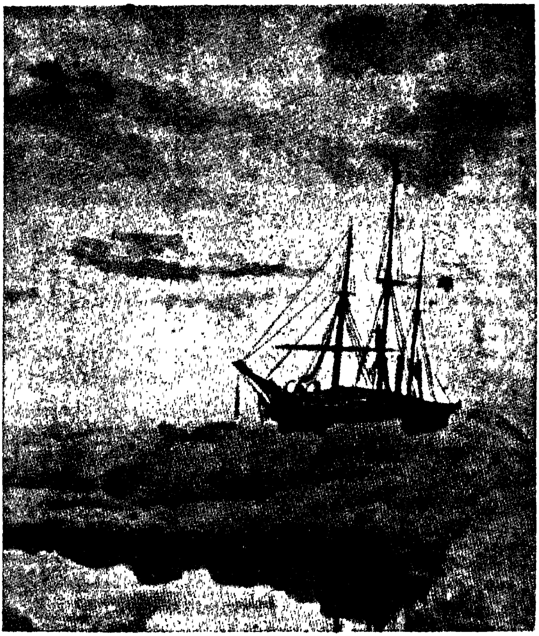

FIG. 19.—THE *FRAM* FROZEN IN THE ICE NEAR THE 82ND PARALLEL. POOLS ARE FORMING ON THE SURFACE OWING TO THE SUMMER MELTING OF THE ICE. (FROM "FARTHEST NORTH.")

incredibly difficult journey over the ice, during which all the dogs were killed one by one,

they at length reached the north part of Franz Josef Land. Here they passed the winter in a hut built of stones and earth, and roofed over with walrus skins. Leaving their winter quarters on May 19th, they made their way southwards, sometimes sailing in their kayaks, at other times hauling the sledges over the ice, to Cape Flora, where, on June 17th, they fell in with the members of the Jackson-Harmsworth expedition, and once more could enjoy the comforts of civilization. On July 26th the *Windward* arrived with stores for the winter, and in her Nansen and Johansen sailed for Norway, arriving at Vardo only a few days before the return of the *Fram*.

The scientific results of the expedition were of the highest importance. Instead of forming a solid, immovable cap round the Pole, it was shown that the ice is constantly breaking and continually drifting onwards towards the Atlantic. Quite unexpected too was the discovery of the great depth of the Polar Sea; hitherto it had been regarded as a comparatively shallow basin, but on more than one occasion, the soundings of the *Fram* showed over 2,000 fathoms. Beside these results, numerous magnetic, astronomical, and meteorological observations of the greatest value were made, as well as measurements of the thickness of the ice, and determinations of the temperature of the sea at various depths.

We have still to consider those great floating masses of ice which are sometimes found

drifting in quite low latitudes, viz. icebergs (Fig. 20). The manner in which they are formed, by breaking off from the terminations of the great Greenland and other glaciers in the Polar regions, has already been described. Floating masses of floe-ice rarely travel any considerable distance southwards, but icebergs, in consequence of their greater bulk, often drift hundreds of miles before they are finally melted. In summer, icebergs, brought

FIG. 20.—AN ICEBERG OFF THE COAST OF SPITZBERGEN.—*Garwood.*

down by the Greenland currents, are common in the Western Atlantic as far south as the latitude of Turin, while occasionally they have been carried to the Azores.

The great size which is sometimes attained by icebergs shed from the glaciers of Greenland is remarkable. Dr. Hayes saw one stranded to the north of Melville Bay which he estimated to weigh two thousand million

tons; it was aground in water half a mile deep. Another, described by Ross, stranded in 250 fathoms of water, measured over two and a quarter miles in length, and two miles in breadth. Even far south in the Atlantic icebergs are often met with more than a hundred feet in height, and it must be remembered that there is about eight times as much ice below water as there is above. (Fig. 21).

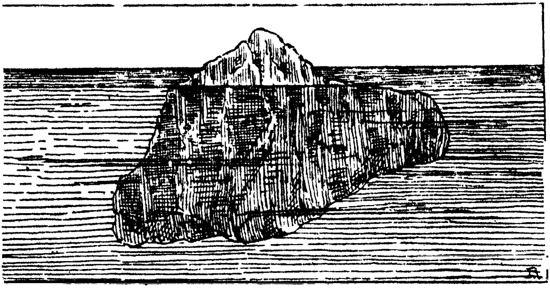

FIG. 21.—FIGURE SHOWING THE PROPORTIONS OF AN ICEBERG ABOVE AND BELOW WATER.

Owing to their size icebergs often project into ocean-currents, which are flowing at a considerable depth, and they are sometimes seen driving along against the wind and surface-flow of water. Dr. Kane, by anchoring his ship to an iceberg, was on one occasion able to proceed northwards, when both the wind and surface-current tended to carry him southwards.

The icebergs of the North Atlantic are of

all sizes and forms, often carved into shining peaks and valleys, or hollowed out into caverns in which a beautiful play of green and blue colours is seen. In the Antarctic Ocean they are generally of a tabular shape with lofty, vertical walls. Frequently the more rapid melting of one part of an iceberg or the breaking off of a large piece, causes the whole mass to roll completely over. This "turning turtle," as it is called by sailors, is a source of great danger to a ship in the immediate vicinity.

Most of the Greenland icebergs are fairly free from earthy débris, but those which break off from the extreme edges of the glacier often carry away a considerable load of earth and stones. These, when the iceberg, finally melts, are tumbled into the ocean. The floor of the North Atlantic must be thickly strewn with boulders and rocks-fragments carried by the ice from lands within the Arctic Circle.

We shall conclude this chapter with a brief description of a curious form of ice, known as *ground-ice*, which has been observed to occur, under certain conditions on the bottoms of rivers and lakes. It is at first held in its place by the reeds and stones around which it is formed; but when the masses of ice attain a sufficient size, they break away from the links which hold them down, and float up to the surface. In this way great blocks of stone are sometimes torn from the river bed. Such ice has also been observed to form in the sea;

where, from the fact that it often adheres to anchors, it has received the name of "anchor-ice." In the Baltic, for instance, before it is frozen over, little floating cakes of ice are often seen with sand and small pebbles, brought up from the sea bottom, embedded in them. Off the coast of Labrador, ground-ice is formed at a considerable depth, and seals, frozen solid, have sometimes been brought up by the fishermen entangled in their lines.

Ice in the Past.

CHAPTER VII.

TRACES OF THE VANISHED GLACIERS.

WHEN we were describing the glaciers in the valleys of Switzerland, we noticed, more than once, that there are indications of the ice having formerly extended considerably below the point at which it now terminates. A merely temporary advance of the glacier will not suffice to explain the great distance which separates the lowest moraines from the termination of the ice, or the wide tract of glaciated ground occupying the intervening space; they are the memorials of a time when a much larger volume of ice filled the valley. In the other mountain chains of Europe, which are of sufficient size to nourish glaciers, similar facts can be recognised. The ice-streams, for instance, of the Pyrenees and the Caucasus, are but shrunken remnants of their former greatness. But the process, in some cases, has been carried still further. In many of the mountainous regions of both Europe and North America, from which every trace of ice has vanished, the former presence of

glaciers is revealed by the silent but indubitable testimony of the rocks over which they passed, and the deposits they left behind in their retreat. Although time has softened down many of the prominent features produced by the ice, and has clothed the scarred surface of the rocks with vegetation, the former limits of the glacier can often be recognised with almost as much exactitude as if it occupied the valley to-day.

Many of the effects wrought by the ice of the past can be readily recognised as such, by their identity with features seen in countries where the glaciers, or ice-sheets, are still in possession. This is particularly the case among mountain regions, where the scratched and polished rocks, the transported boulders, and the moraines, are as clearly the work of glaciers as they are in Switzerland at the present day. But there are other effects, which, while indisputably the result of ice-action, have given rise to much difference of opinion as to the conditions under which they were produced. Broad sheets of material, for instance, are found covering extensive areas of low-lying ground in both the Old and the New World. These cannot be exactly paralleled by any modern deposit, and their formation has in consequence been attributed to various processes; some geologists holding that they are the work of floating ice, while others consider that they were formed on land beneath a glacier or ice-sheet. Finally there are effects which have not been directly pro-

FIG. 22.—A GLACIATED VALLEY, SHOWING MORAINE HEAPS, ROCHES MONTONEES, AND TRANSPORTED BOULDERS.

duced by the ice, but have resulted indirectly from modifications of the physical features of the country brought about by the glaciers. Many of the lakes and tarns, which are found in regions that have been glaciated, are of this nature. It will repay us to consider these various traces of the ice of the past a little more in detail.

In valleys which at some former period have been occupied by glaciers (Fig. 22). as, for instance, the valleys of North Wales, Scotland, or indeed, of almost any of the hilly regions of Europe or the northern part of America, one of the most characteristic features is the scratched and polished character of the rock-surfaces. We have already seen that the process of grinding down the rocks is still in operation in the valleys of the Alps. In the valleys of those regions from which the ice has disappeared, time has covered up much of the worn surface, and effaced many of the scratches, yet often the appearances are as fresh as if they had only recently been produced. Rough projections are ground down, and on the smoothed surfaces the scratches vary from fine striæ to deep scores several yards in length. The smooth, rounded bosses of rock lying half hidden by fern and heather have a distinct resemblance to the backs of sheep; they have, in consequence received the name of *roches moutonnées*. Often a most instructive lesson can be gained from the difference in the aspect of the valley when seen from above or from below. On

looking up the valley from its lower end, the sides of the rocks which were protected from the erosive action of the glacier are seen, and everywhere rough surfaces and sharp angles meet the eye; but from above, the appearance is quite different, every projecting corner and edge has been swept away, and nothing but smooth, rounded outlines can be discerned.

The scratches and striæ on the rocks, for the most part, run parallel to the directions in which the glaciers moved, and by making a map of them over a large area the various centres of dispersal from which the ice radiated outwards can be readily recognised.

Another sign of ice erosion which has been extensively recognised in Norway, North Germany, and other glaciated districts is the presence of "potholes" or "giant's kettles," similar to those found in the valleys of Switzerland (Fig. 23). These cavities have been drilled in the solid rock by the long-continued fall of a torrent of water loaded with sand and stones from the surface of the glacier, on to the same spot of the valley floor.

We saw in chapter iv, that large blocks of material which have fallen on to the surface are frequently brought down by the Swiss glaciers, and stranded on the sides of the valleys considerable distances below their original positions, being then known as erratics. Similar power of transport was possessed by the glaciers of the past. In glaciated regions, boulders, often of huge size, are met with, which can be recognised as

having come from a very distant source. In some cases they have even been carried over low ranges of hills. Those boulders which have been very gently set down by the gradual melting of the ice beneath them, often occupy apparently most unstable positions, being perhaps delicately balanced on their smaller ends, or poised on the top of a projecting crag.

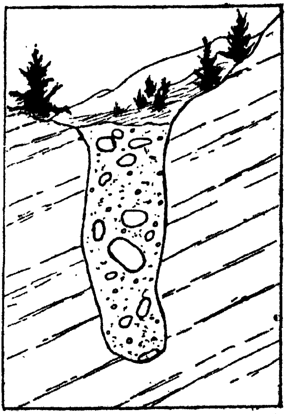

FIG. 23.—SECTION OF A "GIANT'S KETTLE."

Much interesting information can be gained by tracing the distribution of boulders derived from a rock which can be easily recognised. Suppose, for instance, a glacier in its course scrapes against a mass of granite, which contains some peculiar characteristic enabling

it to be distinguished from any otherwise similar rock. The path of the glacier, below the point where it comes in contact with the granite, can now be followed with perfect accuracy by means of the stream of boulders, even after the ice has melted. In some cases, where the rocks on the sides of a valley are of a different character, the two streams of boulders have been observed to remain quite distinct from each other for a considerable distance. Several instances of the possibility of tracing the old path of a glacier by means of the erratics it carried with it, can be seen in the north of England. The glaciers which streamed out from the high ground to the north of the Solway Firth, picked up boulders of Criffel granite, which have been traced all down the coast of Cumberland into Lancashire. Further south, spreading out like a fan, they have been found over the greater part of Cheshire, Staffordshire and Shropshire. To the east of the English Lake District there is an important mass of rock known as the Shap granite, which possesses certain very distinctive features. Boulders of Shap granite show that the ice of this region streamed northwards towards Penrith, southwards to Morecambe Bay, and eastwards right over the Pennines, through Stainmoor Pass, 1400 feet above the level of the sea, thence spreading out all over eastern and northern Yorkshire and down the coast as far south as Holderness.

Besides the scratched rock-surfaces and the

transported boulders, striking evidence of the former presence of glaciers is afforded in many valleys by the mounds and accumulations of material which represent the old moraines. Often a series of ridges, lying one within the other, can be detected stretching, more or less, completely across the valley from side to side. These are the old terminal moraines, each one indicating a pause in the gradual retreat of the ice. Lateral moraines are represented by accumulations running parallel with the sides of the valley. Generally the heaps of glacial material are now smooth and grass-covered, but in places where they have been cut through by rivers, and on slopes too steep for vegetation to grow, their true character can be made out. In some places they consist mainly of coarse gravel and sand, while in other localites they may be formed chiefly of clay; but though considerable variations in the nature of the material of which they are composed may occur, the absence of any distinct stratification, and the frequent presence of stones with their angles more or less rounded and their flat surfaces scratched and polished, usually in the direction of their length, point conclusively to the glacial origin of these accumulations. (Fig. 24).

So far, the traces of ice-action in the past, which we have considered, have been of such a nature that no doubt can exist as to the circumstances under which they were formed. Similar effects may be seen actually in process

of production in Alpine valleys at the present day. The scratched rock-surfaces, transported boulders and moraines, found among the higher mountain regions of Europe and North America, can have been produced only by one agent in nature—a glacier. But when

FIG. 24.—STONE, SCRATCHED AND POLISHED BY THE ACTION OF ICE.

we leave the fairly simple facts presented by a mountain valley, and examine the phenomena which are found on lower ground, we encounter many problems which are extremely difficult of interpretation. Deposits containing undoubted signs of ice-work are met with

covering wide stretches of country, but whether they were formed on land, or beneath the surface of the sea is, in many cases, a very open question. Their great extent, however, shows that a vast area of sea or land was under the influence of ice in the form either of icebergs or glaciers.

Glacial accumulations are found over a large area of the British Isles, over Scandinavia, North Germany and Russia, and in the New World covering vast tracts of Canada and the north-eastern States. To describe all the different deposits met with would exceed the limits of the present work, but some account of the chief types may be given.

One of the most widely-spread deposits is that which is known as *boulder-clay*. It varies considerably in different places, but most frequently consists of a firm, tenacious, stony clay, often so tough that blasting it is impossible, excavations for railway cuttings and other purposes having to be made by slowly picking the material away. The composition of boulder-clay depends largely upon the nature of the rocks beneath it and in the immediate neighbourhood; where it overlies a red sandstone, for instance, it contains a larger proportion of sand and gravel than usual, and is of a red colour.

Stratification, as a rule, is absent or indistinct. The stones embedded in boulder-clay vary in size from the dimensions of small grit up to great masses several yards in length. The latter, however, are rare, and indeed,

boulders over a yard in diameter are not frequently met with. The greater number have been derived from rocks in the vicinity, but some have been carried by the ice from a considerable distance. In the boulder-clays of the East of England, for instance, pebbles occur which can only have come from Scotland; while some have even been derived from so distant a source as Norway. The flat surfaces of many of the stones are scratched and polished, the angles and edges being more or less worn away and rounded.

The most generally accepted view of the origin of boulder-clay is that which supposes it to have been formed beneath large glaciers or ice-sheets, and thus to be comparable with the *moraine profonde* of Alpine glaciers. The striated character of the pavement of rock, upon which the deposit frequently lies, lends additional support to this explanation. But there is no doubt that in some localities floating ice, in the form of icebergs or coast ice, has played an important part in the formation of boulder-clay. The pebbles of Scandinavian rocks, mentioned above as present in the deposits on the east coast of England, are believed by some to have been brought across from Norway by a great glacier which occupied the bed of the North Sea. But many geologists consider that this explanation is not supported by the evidence, and floating ice is regarded as having been the agent of transport.

Associated with boulder-clay there is a

series of deposits extremely diverse both in character and origin. They consist chiefly of beds of sand and gravel, and are found in some places, resting on the boulder-clay; in others, sandwiched in between two layers of that deposit. In a few places, small accumulations of remains of vegetation have been discovered. Some of these beds were laid down in lakes formed upon the surface of the glacier, or held up by moraines, others have been claimed as marine, while yet others have been supposed to owe their formation to the action of running water upon the deposits left by the retreating glaciers. The intercalation of a bed of sand or gravel between two layers of boulder-clay points to a temporary retreat of the ice, followed by a fresh movement forward. The deposits of vegetation may have been formed by the overwhelming of forest-growth in some such position as that which clings to the fringe of the Malaspina Glacier in Alaska.

A remarkable deposit, or series of deposits, known as the *contorted drift*, is particularly well seen overlying the boulder-clay in parts of the east coast of England. It consists of sands, gravels and clays, frequently well stratified, and containing numerous erratics, often of gigantic size. Masses of chalk, several yards long, are frequently present, and they have been observed over 150 yards in length. But the most prominent characteristic is the remarkable series of foldings and contortions which the beds exhibit. For

a short distance the stratification may be perfectly regular and horizontal, then suddenly the beds become twisted and crumpled in the wildest manner, sometimes even being folded right back on themselves.

Much difference of opinion exists as to the cause which produced the phenomena of the contorted drift; but the view which meets with the most acceptance supposes them to have resulted from the pressure of an ice-sheet or glacier upon the underlying beds.

There are certain other glacial accumulations which are variously known as *kames*, *eskers*, and in Sweden, where they are particularly well developed, as *asar*. Frequently they form long ridges or mounds, rising to a height of about thirty to sixty feet above the general level of the ground. Some of them (asar) follow the general trend of the valleys in which they occur; but others (kames) can often be traced for miles across the country, running up hill and down dale in a manner which shows them to be largely independent of the drainage lines of the district. They are composed chiefly of sand, gravel and shingle, the stones of which are all more or less waterworn. Stratification is frequently well developed. Water action is generally admitted to have played a large part in the formation of these ridges, but their exact mode of origin is still a matter of discussion. It seems probable that asar were deposited by rivers flowing on the surface or within the mass of a glacier, and are thus comparable with the

accumulations at present in course of formation on the Malaspina Glacier. Kames may have resulted from the action of the great volumes of water which flowed from the terminations of the melting glaciers. Some authorities, however, consider that marine action was the chief agent in the formation of these deposits. Certain lenticular hills, known as *drumlins*, which are well-developed in the neighbourhood of Boston (Mass.), present many features in common with kames and äsar, and are equally difficult to account for satisfactorily.

Besides the deposits and other traces left by the glaciers, their influence may be detected in various changes which they have indirectly brought about in the physical features of a country. Modifications, for instance, have been frequently introduced into the drainage system of a valley or region. The piling up of a mass of material across a valley may give rise to a barrier, which persists, after the ice has melted, blocking up the stream. The water then rises behind the dam forming a lake, which may find an exit over the glacial material, or through a lateral valley, or perhaps, even over the col at the head; while below the barrier stretches the old water-course, now, perhaps, completely dry, or at the most containing only an insignificant stream. Several instances of this kind of action have been pointed out by Mr. J. E. Marr in the English Lake District, perhaps the most striking being that furnished

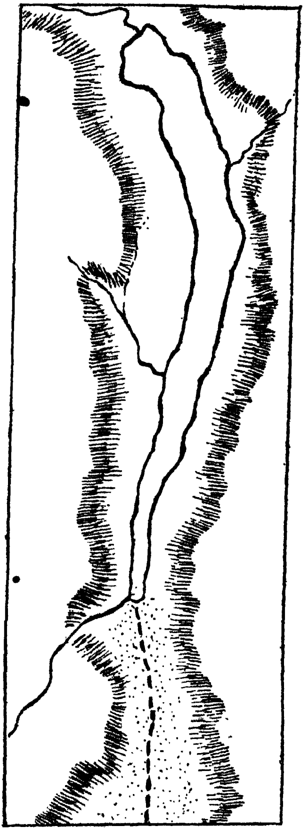

FIG. 25.—DIAGRAM SHOWING THE DRIFT-FILLED VALLEY AT THE LOWER END OF WINDERMERE. THE DOTTED LINE INDICATES THE OLD COURSE OF THE STREAM.

by Windermere. (Fig. 25). This beautiful sheet of water, the largest in the district, lies in a trough about twelve miles long, running north and south. At the lower end, the river, which drains the lake, makes a sudden bend to the south-west, and pursues its way towards the sea through a narrow rocky gorge; but in the same straight line with the Windermere valley, and forming a continuation of the lake-basin, is the broad Cartmel valley, now occupied by only an insignificant stream. The floor of the Cartmel valley and the col at the head of it, separating it from the lake, are both covered with glacial drift, and there is little reason to doubt that, at one time, the Windermere valley was occupied by a river which maintained a straight course to the sea; but that, owing to the blocking up of the lower part of the valley, the drainage was diverted into the narrow channel running towards the south-west and the lake formed above the dam.

A usually very characteristic feature of regions which have been glaciated, is the presence of numerous lakes and tarns, scattered over the surfaces. This is well seen in Scandinavia and in the hilly districts of the British Isles. Among the mountain chains of North America, thousands of lakes occur, varying in size from small pools up to sheets several miles in length. A large proportion of these, especially of the smaller lakes and tarns, owe their origin to the blocking of valleys by glacial material.

The view was formerly held that the majority of the lakes of glaciated districts owe their origin to the actual scooping out of the solid rock by the ancient glaciers. Sir Andrew Ramsay, who first put forward this hypothesis from observations on the Alpine lakes, gave such hollows the name of *rock-basins*. The numerous long narrow fiords, which indent the coasts of Scotland and Scandinavia, were ascribed to the same process. But later observations have shown that many of the supposed rock-basins have really been formed by movements in the earth's crust; while others have been proved to be the result of the blocking up of valleys by drift. In those cases, where the dam is narrow, and the stream has been diverted so as to flow out over the solid rock only the most careful investigation will reveal the true nature of the lake. Mr. Marr has pointed out that some of the tarns in the English Lake District at first sight appear to be undoubted rock basins; but in almost every case glacial material can be detected in some part or other, interrupting the continuity of the rocky margin round the lake. In one case, the drift-dam was only ten paces across. It is possible, that under favourable conditions, a glacier was able to scoop out a slight depression in the rocks; but that the process took place to anything like the extent that was formerly believed, is now generally denied.

While on the subject of the relations sub-

sisting between glaciers and lakes, it is interesting to note that, in more than one locality, proofs have been obtained of the former existence of lakes of a temporary nature, comparable with the Märjelen See on the Great Aletsch Glacier, described on page 60. The best known traces of such a lake are those which form the celebrated "Parallel Roads" of Glen Roy in the western highlands of Scotland, not far from Ben Nevis. They consist of three horizontal shelves or terraces, each about twenty yards in width, which run along both sides of the glen for nearly its whole length, curving round also into all the minor hollows in the sides of the valley (Fig. 26.) The remarkable uniformity in the roads for long caused them to be regarded as the handiwork of man, and the country people formerly believed that they had been made by the giant Fingal and "were designed for the chase, and that the terraces were made after the spots were cleared in lines from wood, in order to tempt the animals into the open paths after they were rouzed, in order that they might come within reach of the bowmen, who might conceal themselves in the woods above and below." The highest terrace is about 1,150 feet above the level of the sea, the second about 1,065 feet, and the third 855 feet. They are formed of angular or slightly-rounded fragments derived from the slopes above, and contain no fossils except a few fresh-water algæ. In the neighbouring valleys of Glen Gluoy and Glen Spean, similar terraces are

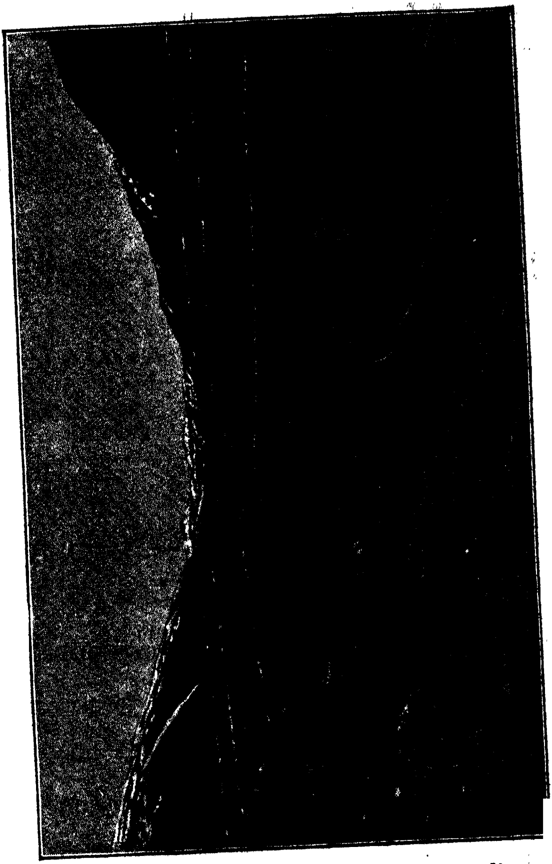

FIG. 26.—THE "PARALLEL ROADS" OF GLEN ROY.

found, but these are usually not quite so perfect.

It is admitted by all authorities that the parallel roads are really old beaches, accumulated at the margins of sheets of water which formerly occupied the valley, to different levels. One fact in support of this view may be mentioned. At several points in the centre of the glen, isolated hills arise, which would have stood up as islands in the old lake or fiord; encircling these hills the three terraces are found, at precisely the same elevations as on the sides of the main glen. It was at one time supposed that the beaches were formed by the action of the sea, at a period when the land stood at a lower level than it does at present; each one marking a pause in the process of re-elevation; but there is little evidence in support of this theory, and the explanation now generally accepted is that the water was held up by great glaciers which descended from the heights of Ben Nevis, and blocked up the end of Glen Roy and the side valleys which open into it. At first the exit of the lake was over the col at the head of Glen Roy, and during this period the highest beach was formed. But as the barrier of ice gradually melted and retreated backwards down the valley, a communication was at length established between Glen Roy and one of the side valleys, and the lake rapidly fell to the level of the second terrace. After a long pause, a still lower channel of escape was opened, and the lowest terrace was then built up.

To summarise then, there are to be found, scattered over the greater part of Northern Europe and America, scratched and polished rock-surfaces, transported boulders, moraines, sheets of glacial material, and other indications of the former presence of glaciers or ice-sheets in regions where now, save during the winter frosts, no trace of ice is to be found. In addition, the influence of ice may be detected in peculiarities of the drainage system, and other physical features of the countries over which it lay. Before the true character of these phenomena was recognised, many erroneous hypotheses were put forward to account for them. It was supposed, for instance, that numerous gigantic waves, started by some mysterious process in the far north, swept over the land with irresistible force, churning up the loose material on the surface and scratching and polishing the rocks as they passed over them in their wild careet. When the waters had subsided, extensive sheets of stony clay and mud, or "drift," were left spread out over the lowlands; while many large boulders had been stranded in isolated positions on the hillsides. Further evidence, in support of this view, was found by some in the traditional account of the Deluge. The celebrated Agassiz was among the first to attribute the phenomena to their *vera causa*, land-ice; and the researches of subsequent geologists have proved beyond all doubt that they are the traces of a prolonged period, during which, low temperatures

prevailed, and the greater part of the Northern Hemisphere presented conditions of Arctic severity. It is this chapter in the world's history which is referred to as the *Glacial Period* or *Ice Age*.

CHAPTER VIII.

THE POSITION OF THE ICE AGE IN THE GEOLOGICAL RECORD.

In the last chapter we considered the evidence upon which belief in the Ice Age rests. Before proceeding to discuss the conditions, which prevail over Europe and America at this time, it will be convenient to try and determine a little more definitely when the Ice Age occurred, instead of merely vaguely referring it to "the past." In order to do this satisfactorily, we are obliged to go back to those periods of the world's history which preceded it, and we are then able to follow the gradual increase in the degree of cold, through successive ages from the first perceptible lowering of temperature to the culmination in the Ice Age.

Written records extend back over a period of some six thousand years. Traces of a primitive civilisation, of probably an even earlier date, still remain in certain ruined temples and monuments on the banks of the Nile and in parts of Asia; but the men who built them had not yet learnt to write. Beyond this period it is impossible to make more than the merest guesses as to the number of years which has elapsed since any given event. But though the precise intervals of time cannot be told, the various events

as they succeeded each other can be arranged in chronological sequence, a table being thus formed by means of which comparisons are effected. Geologists have succeeded, from the evidence of fossils and other records preserved in the rocks, in dividing the long prehistoric ages into a number of periods, each of which has been again divided into lesser intervals. Climatal and other changes can, by means of this record, be assigned to their proper positions in the history of the world.

The rocks which form the solid crust of the globe fall, broadly speaking, into two great classes, those which are stratified and those which are not. To the unstratified class belong igneous rocks, such as lava or granite, and also a series of rocks known as gneisses, which cover vast areas in both the Eastern and Western Hemispheres. The latter were produced long before the appearance of any forms of life upon the globe, and some of them may even represent the earliest crust which solidified as the heated mass cooled.

The stratified rocks were, almost without exception, laid down under water. As a rule they contain the remains of plants or animals which flourished during past ages, and these fossils exhibit a gradually-increasing degree of complexity, from the comparatively simple organisms found in the oldest rocks up to the highly specialised forms of to-day. The period during which the stratified rocks were being deposited, has

been divided into four great epochs, and each of these has been sub-divided into shorter intervals. Although in geological tables these divisions appear to be quite separate and distinct from each other, we must not fall into the error of supposing that in nature any sharp lines of division exist between them, or that at each new period a different set of conditions prevailed, and a fresh series of animals came into existence. On the contrary, each period merged quite gradually and insensibly into that which succeeded it; and although in books it is necessary to separate them, generally defining the lines by the presence or absence of some particular fossil or group of fossils, it must be remembered that these divisions are really quite artificial.

The following table exhibits the subdivisions of the stratified rocks:—

Quarternary or Post-Tertiary.	Recent. Pleistocene.
Tertiary or Cainozoic.	Pliocene. Miocene. Oligocene. Eocene.
Secondary or Mesozoic.	Cretaceous. Jurassic. Triassic.
Primary or Palæozoic.	Permian. Carboniferous. Devonian. Silurian. Cambrian. Pre-Cambrian.

The oldest of the four main divisions, the Palæozoic or Primary period, was by far the longest. It was characterised by the existence, especially during its early stages, of comparatively simple forms of life. In the lowest deposits no trace—either of land animals or plants—has been found, but the remains of marine organisms, such as shell-fish and crustacea are abundant. At a rather later stage, fishes, the earliest forms of vertebrates, made their appearance. Towards the end of the period the growth of terrestrial vegetation seems to have become very vigorous, and dense forests were formed, consisting chiefly of ferns and huge trees of a not very highly developed character, allied to the modern club-mosses and horse-tails. The carbonised remains of this vegetation now constitute most of the great coalfields in both the Eastern and Westen Hemispheres. Among the lagoons were the first land-vertebrates, amphibia with marked, fish-like characters.

The Mesozoic period has been termed "the age of reptiles," for on both land and sea forms of these creatures existed in great abundance and variety. Higher and more specialised types were constantly appearing. The earliest traces of mammalian life, the teeth and bones of some small marsupials, are found in rocks of Triassic Age; while the remains of the first known bird, a curious form with sharp teeth, a long, tapering, bony tail and other reptilian characters, have been discovered in Jurassic formations. Plants,

likewise, are more advanced; cycads and conifers are the most numerous forms, and in the latest stages dicotyledons also become abundant.*

With the Tertiary period we get an approach to the conditions which characterise our planet at the present time. The abundant reptilian life of the preceding epoch was largely reduced, but its place was taken by an extraordinary assemblage of mammalian forms, far exceeding, both in number and diversity of character, those now living on the surfact of the globe. The ancestors of modern animals were present, and associated with them were remarkable types, whole groups of which have since become extinct. Among the plant remains, representatives of all the higher groups have been found. It was during the Tertiary period that most of the mountain chains of the Old World, from the Pyrenees on the shores of the Atlantic to the giant ranges of the Himalayas, and the mountains of Eastern Asia, were upheaved.

The Quarternary period is, in the matter of time, by far the shortest of the four great divisions, but being associated, as it is, with the early history of the human race, it possesses, perhaps, the greatest amount of interest. The initial stages were characterised by that marked decline in temperature of which we have already considered the evidence. As a result of the cold, great havoc was wrought upon the rich and varied animal life of Tertiary times; many genera

and species were exterminated, so that the fauna of to-day is but an enfeebled representative of that which preceded it. "We live," says Dr. Wallace, "in a zoologically impoverished world, from which all the largest, and fiercest, and strangest forms have recently disappeared." The later stages of the Quaternary period are the history of the last geographical and other changes which gradually led up to the prevailing conditions. Man increased in number and progressed in intellect, until he invented the art of writing, and thus linked the closing age of the geological record with the dawn of the historic period.

Attempts to determine the character of the climate, which prevailed during any period in the past history of the earth, are generally based upon the nature of the fossil plants and animals found in the deposits laid down at the time. Thus, for instance, if the majority of the forms of life belong to such types, the nearest representatives of which now inhabit equatorial regions, there is strong evidence that they flourished under a warm climate. If, on the other hand, the plants are small and stunted, and the animals have thick woolly coats and other characteristics of northern forms, it is probable that cold conditions prevailed. It naturally follows that the more recent the period, the more likely are we to form a correct opinion as to its climate. In proportion as we recede from the present, the greater does the deviation of

the animals from familiar forms become, and consequently the greater is the difficulty of judging accurately the climatal conditions essential for their existence. Within the Polar Circles, however, the mere presence of certain fossils can often be regarded as indicative of a warm climate. In Spitzbergen, for instance, abundant plant-remains of Carboniferous age and also of Jurassic age have been found embedded in the rocks beneath the frozen soil. It is hardly to be supposed that these plants, although they differ very considerably from their modern descendants, flourished under Arctic conditions; and the existence of a mild climate in Spitzbergen probably indicates proportionally higher temperatures in regions further south.

In the case of a climate sufficiently cold to load the country with glaciers, we have already seen that besides any information to be derived from the fauna and flora, additional evidence of the low temperature may exist in the form of glacial deposits and other traces of ice-action. At two periods of the world's history has the existence of widely-spread cold conditions been inferred from evidence of this description. The first of these occurred as far back as Permian times, and the effects appear to have been confined, so far as is at present known, to the Southern Hemisphere. The second cold period was that which marked the earlier stages of the Quaternary epoch, and which has been already referred

to as the Ice Age. It is possible, that during other periods in the geological record, cold conditions prevailed, and indeed, traces of ice-action have been claimed or suggested as existing, at some place or other, in almost all the various systems. But in the majority of these cases the evidence is extremely doubtful, and, at the best, seldom indicates more than the existence of floating masses of ice such as are now met with in quite low latitudes. There is no evidence of the occurrence of anything like a glacial period beyond the two instances mentioned. It must be remembered, however, that the records of an ice age, the deposits, moraines and markings on the rocks, lying, as they do, upon the surface of the land, are exposed to the action of wind and weather, and are thus liable to be swept away in a space of time which, from a geological point of view, must be regarded as short, though doubtless extending over many thousands of years. The abundance of the traces of the Quaternary glacial period, and the excellent state of preservation which they exhibit, constitute a proof of the lateness of their formation.

The artificial character of the divisions which separate the different geological periods has already been pointed out. In nature, each one passed perfectly, gradually, and insensibly into that which succeeded it. So, also, was this the case with the Ice Age. The interval of time, to which this term is applied, was really the culminating

period of a change which had been slowly coming on for long ages previously; not a period commencing with a sudden fall of temperature, and terminating after a certain lapse of time in an abrupt return to milder conditions. The first indications of the approaching Ice Age must be sought for as far back as Mid-Tertiary times; while in the shrinking glaciers of the Alps, the last traces of it may still be said to exist.

Let us endeavour to trace the gradual decline of temperature which preceded the Ice Age, as revealed by the fossil evidence preserved in the rocks.

In Eocene, Oligocene and earlier Miocene deposits there are abundant indications that the climate of Europe was, at the time they were laid down, of a tropical or sub-tropical nature, the modern representatives of many of the plants and animals being now only found in such warm countries as India or Australia. In the forests flourished numerous bananas, gum-trees, screw-pines, cinnamons, varieties of the ebony tree, and graceful fan and feather-palms, all forms now confined to tropical regions. The screw-pine is at present only found in the islands of the Indian Ocean. Others, characteristic of a warm climate, were figs, spindle-trees, magnolias, vines, bays, acacias and sequoias. The last, the giant tree of California, had a wide distribution over both Hemispheres. Mingled with these were many of our familiar trees, such as planes, elms, beeches,

willows, poplars, maples and chestnuts. The large proportion of trees and woody plants is very striking, and at once suggests the prevalence of a warm climate. In a tropical or sub-tropical zone, woody plants are abundant, the wood serving to give the plants that firmness which they require to support their luxuriant growth of leaves and branches.

The animal life equally indicates the warm character of the climate. In the seas were large volutes and numerous other tropical shells, as well as sea-snakes, and in the south of Europe reef-building corals; while the rivers and lakes were tenanted by tortoises, turtles, crocodiles, and fish resembling those now living in India and Equatorial Africa. The bird-remains obtained from the lacustrine deposits of central France include forms of pelicans, ibises, hornbills, cranes, grouse, secretary-birds and flamingos, an assemblage resembling that which haunts the shores of the South African lakes. Through the jungles roamed many strange animals, some of great size. The *deinoceras*, from the Eocene beds of the Rocky Mountains, attained the size of an elephant, and was armed with three pairs of horns, as well as long, sabre-like, canine teeth. In addition, there were numerous early forms of the deer, tapir, and monkey.

Some remarkable evidence exists of the prevalence of warm conditions, even well within the Artic Circle, during early Tertiary times. In lands where now but the sparsest

vegetation manages to subsist, traces of a luxuriant plant-life, characteristic of a warm, temperate zone, have been discovered. In Greenland, as far north as latitude 70°, remains of maples, limes, poplars, oaks, beeches, walnuts, even magnolias and palms, as well as numerous conifers, have been discovered. That these grew on the spot, and were not drifted there from more southerly regions, is proved by the presence of their fruits in every stage of growth. In Spitzbergen, also, thick forests must have existed consisting chiefly of conifers. But, perhaps, the most striking find was that made during the expedition of the *Alert* and *Discovery*, of a bed of black, lustrous coal, in Arctic North America beyond the eighty-first parallel. Here again conifers predominated, especially pines, firs, spruces and cypresses, but remains of birches, poplars, elms and hazels, were also found. On the borders of the lakes grew water-lilies, reeds and sedges. Speaking of these discoveries, Sir Archibald Geikie says, "When we remember that this vegetation grew luxuriantly within 8° 15′ of the North Pole, in a region which is now in darkness for half of the year, and almost continually buried under snow and ice, we can realise the difficulty of the problem in the distribution of climate which these facts present to the geologist."

The warm climate, of which there is such abundant evidence, appears to have prevailed all through Tertiary times up to the middle

of the Miocene period; but in the later deposits of that age the first indications of the approaching change may be detected. The flora is still essentially the same, but the most tropical plants have disappeared from it. The palms have gone, while the more temperate types, the elms, beeches and poplars, have increased in numbers and now form a larger proportion of the forests.

At the beginning of the succeeding age, the Pliocene period, the decline in temperature had become distinctly marked, all the plants most characteristic of a tropical zone having disappeared. But there is ample evidence that the climate was still considerably warmer than at present. Remains have been found of the bamboo, liquidambar, maple, tulip-tree, sumach, cinnamon, rose-laurel, magnolia, plane, evergreen-oak, and other familiar trees, a flora thus intermediate in character between the luxuriant sub-tropical assemblage of Miocene times and that of modern Europe. Animal life was represented by many large mammalia, among which were the mastodon, elephant, rhinoceros, and fierce, sabre-toothed tiger, while hippopotami haunted the rivers.

In the later deposits of the Pliocene period there is evidence that a still further change had occurred, and that the climate of Europe had, in all probability, come to be very much what it is at the present day. From a group of strata on the east coast of England, known as the "Cromer Forest-bed," a number of plants have been recovered,

nearly all of which are well-known types still growing in Britian. Among the trees were birches, alders, hazels, oaks, and beeches, while in the fields and marshes grew buttercups, royal-ferns, marsh-marigolds, sedges, yellow and white water-lilies, and other common wild-flowers of to-day. In contrast, however, with this familiar flora, the animal life presented a strange appearance. Elephants, rhinoceroses and hippopotami were abundant as well as bears, wolves, and other carnivora; in the seas, significant of the cooler conditions, were seals, whales, and walruses, and among the mollusca several northern forms made their appearance.

At the very top of the Pliocene deposits in the east of England is found a bed the fossils of which indicate that Arctic conditions had at last set in. Trees are completely absent, and the vegetation now consists entirely of mosses and the dwarf Arctic birch and willow, stunted forms such as are now found growing in Spitzbergen and other lands round the Pole, rarely attaining a height of more than two or three feet. The only other fossils are a few land and fresh-water shells, some wing-cases of beetles and remains of the souslik, a small, marmot-like rodent now found living in Siberia. The climate of Western Europe must, at this time, have been very severe. Probably during the winter months the bays and fiords round the coast were locked with ice, and the rivers were thickly frozen over; while in

the hilly regions glaciers had begun to creep down the mountain sides.

Lying immediately above these traces of an old land-surface are the various boulder-clays, moraines and other accumulations of the Glacial Period.

There is then, in the fossil remains of both the animals and plants, evidence of a gradual decline in temperature from the tropical conditions under which the early Tertiary deposits were laid down to the Arctic severity of the Ice Age. We have already considered the evidence from which the existence of this period of cold has been deduced. In the next two chapters we shall endeavour to realise what were the conditions which prevailed in both the Eastern and Western Hemispheres until it passed away.

CHAPTER IX.

THE ICE AGE IN THE OLD WORLD.

In the Old World the most conspicuous traces of the Ice Age are to be found in those countries which form the northern and western portions of Europe; but indications of the lowering of temperature are not wanting in the more southerly parts of that continent, and among the great mountain chains of Asia and Africa, even in latitudes but a few degrees from the Equator.

Of the British Isles, the area which was most severely glaciated was Scotland. The Highlands, the Southern Uplands, and probably the whole of the Lowlands, were buried beneath a sheet of ice, from above which only the tops of the highest mountains projected. From the margin of this *mer de glace* tongues of ice pushed their way down the glens and out into the sea. In some places the proofs of the glaciation are most impressive. Scratches may be traced from the low ground up to elevations of at least 3,000 feet. Surfaces of rock, ground and polished by the ice which swept over them, may be seen in every direction. Some of the smaller hills are in reality nothing more than huge *roches moutonnées*; Suainabhal, for instance, a mountain on the west coast of Lewis, 1,300 feet in height,

has been worn by the ice from base to summit. Professor James Geikie has estimated the thickness of the ice-sheet, which produced these effects, at not less than 3,000 feet. Many of the islands round the coast were also covered by the ice, the striae often running right across them, and not radiating from the centre, as would have been the case if they had given rise to independant glaciers. The mountains of Skye, however, appear to have formed a separate centre of dispersal.

In England, the hilly regions to the west became extensive gathering-grounds of snow from which glaciers radiated outwards. We have already seen how it is possible to trace the paths of these by means of the erratics they left stranded on the hillsides and plains when they melted. From evidence of this description it has been inferred that glaciers streamed out from the south of Scotland, the Lake District and the north-west of Ireland down into the sea, and there coalesced to form one huge mass which has been termed the Irish Sea glacier. Sweeping down from the north, it encountered the ice from the mountains of North Wales, which, though partially driven back, compelled the invader to divide into two branches, one of which crept over the midland counties of England, while the other travelled down the bed of the Irish Sea and perhaps passed over St. David's Head. Another branch of the Irish Sea glacier forced its way up the Solway Firth and over the low-lying grounds of North Cumber-

land as far as Cross Fell. Here it was divided into two streams, one of which pushed its way eastwards down the valley of the Tyne and ultimately flowed into the North Sea near Tynemouth. The other, turning southwards, made its way up the valley of the Eden, and picking up boulders from Shap went right over the Pennines through Stainmoor Pass at an elevation of some 1,800 feet. From this point the ice spread out over the low ground, scattering masses of Shap granite over a large area of northern Yorkshire, and a portion eventually reaching the sea near Hartlepool.

It must be observed that this explanation of the distribution of the erratics in northern and central England is not universally accepted. Some geologists hold that the land, though at first rather higher than it is at present, sunk during the Glacial Period until in Wales at least the submergence amounted to some 1300 feet. The erratics were then transported to their present positions by means of floating ice. At a later period, on re-elevation, the moraines and other undoubted traces of land-ice were produced by comparatively small glaciers which were formed in the valleys. Into the arguments for and against this view it is impossible to fully enter here; but one fact, around which great controversy has centered, may be mentioned.

Many years ago, certain beds of gravel, sand and clay were discovered on Moel Tryfan, a mountain near the west coast of

Carnarvonshire. The sandy parts contained marine shells, nearly all of which were crushed and broken. The highest of these beds is 1,350 feet above sea-level. Later discoveries have proved the existence of beds containing fragments of marine shells at heights of from 150 to 1,200 feet, in Lancashire, Cheshire, Shropshire, and the adjacent counties. Geologists who support the submergence theory, consider that these beds are true marine deposits laid down beneath the sea. On the glacial theory the beds are regarded as patches of the sea-bottom, which were scooped up by the glacier, carried on to land, and laid down high up on the mountain side. Improbable, as this view may at first sound, it derives great support from observations such as these made by Mr. E. J. Garwood and Dr. J. W. Gregory in Spitzbergen, to which we have previously referred. Here, apparently, the process of a glacier raising material from a low to a high level may be actually seen in operation, although the ice itself does necessarily move uphill.

In the less hilly parts of England and Wales, moraines and other mountain types of glacial accumulations are not so well marked, but their place is taken by the remarkable series of boulder-clays, contorted drift and other deposits of which we gave some account in chapter VII. On the coasts of Yorkshire, and the eastern counties, splendid sections of these beds may be seen. They also cover large areas of the Midlands, extending as far

south as the northern margin of the valley of the Thames. Speaking generally, a division of the series into an upper and lower boulder-clay, with a deposit of sands and gravel between them, can be recognised on both the east and west sides of England. But this arrangement is liable to considerable variation. Sometimes the sands and gravels are absent, and the two boulder-clays coalesce. In other places the lower or upper boulder-clay may be absent. In the Midland counties and on high ground the separation is usually indistinct, the boulder-clays rarely occurring at greater heights than 800 feet above sea-level.

While these deposits are admitted by all authorities to be indubitably the work of ice in some form or other, there is considerable diversity of opinion as to the manner in which they were formed. Some geologists hold that the sands and gravels, and most of the boulder-clays were laid down under water during a period of submergence, and that the scratched stones and rock-fragments were dropped into them from icebergs and floating masses of shore-ice. Others, however, consider that the boulder-clays are deposits which were formed beneath great sheets of land-ice, being in fact, the ground moraines of huge glaciers. The better-stratified gravels were laid down in large lakes; while others consist of glacial material, re-arranged by streams and floods, perhaps during a temporary recession of the ice.

The belief that the Glacial Period was interrupted by one or more intervals, during which milder conditions prevailed, has been upheld by a considerable school of geologists, Professor James Geikie, in the last edition of "The Great Ice Age" (1894) going so far as to describe five such warm intervals. The separation of beds of boulder-clay by sand and gravel undoubtedly indicates climatic variations, perhaps of considerable extent. But most authorities now consider that the phenomena can be explained by assuming temporary recessions of the ice, similar to those observed among the Swiss glaciers, but on a larger scale, not, however, of sufficient magnitude to be regarded as constituting an "interglacial" period.

One of the facts which have been looked upon as evidence of a warm interglacial period, is the occasional presence in the Scottish Lowlands and on the continent of Europe of beds of peat and lignite, sandwiched between two layers of boulder-clay. Usually they are associated with layers of gravel, sand or clay (Fig. 27.) Many of these deposits were accumulated at the bottoms of lakes or ponds, and evidence of this is seen in the trough-shaped hollows or depressions in the till in which they lie. In some cases, remains of fresh-water organisms, such as caddis-caves and jaws of leeches, have been found in the peat and silt.

Among the remains discovered in these beds are the leaves, twigs and seeds of many

orest trees, such as the oak, alder, pine, willow and birch, the last two being chiefly represented by the dwarf Arctic forms. Ferns are absent, but a few flowering plants, such as the buttercup and lychnis occur. All the plants found in the Scotch deposits are such as have a considerable range northwards at the present day.

At first sight it seems difficult to reconcile this forest growth with anything except a mild climate; but we have already had more than one instance of the growth of even dense

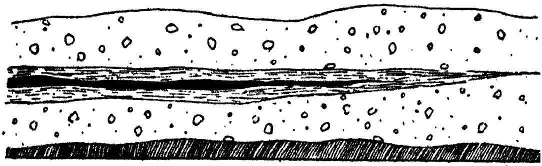

FIG. 27.—SECTION THROUGH A SERIES OF GLACIAL DEPOSITS, SHOWING A LAYER OF VEGETABLE DEBRIS AND SANDY BEDS, INTERPOSED BETWEEN TWO MASSES OF BOULDER-CLAY.

vegetation in close proximity to glaciers. In describing the great Agassiz glacier, in Alaska, Mr. Seton-Karr writes, "Under these piles of moving stones, which are for ever being carried forward, lies the glacier ice three or four hundred feet in thickness at the edge and much thicker elsewhere; while a tangled forest of Spruce and Birch, Maple and Alder is growing along its extremity, so thickly and closely that it becomes exceed-

ingly difficult, especially to men with large packs on their backs, to force a way through." The decaying vegetation is gradually forming a bed of peat, and, if in time to come, an extension of the glacier should overwhelm this with a layer of boulder-clay, the series of deposits might be taken as indicative of two periods of cold separated by a warm interval. The plants found on the Greenland Nunataka, the rocky mountain tops which project up through the ice, furnish another instance of vegetation growing under Arctic conditions. It is quite possible, therefore, that the vegetation, the traces of which have been found in Scotland and other countries, does not indicate anything like a general amelioration of the climate, but shows that throughout the Ice Age trees and plants managed to subsist in sheltered spots, and that occasionally, during temporary small retreats of the glaciers, they were able to spread over deposits previously laid down.

On the continent of Europe, the countries lying to the north-west were naturally subjected to the severest glaciation. The high table-land of Scandinavia became a great centre of dispersal, from which the ice radiated outwards in every direction ; on the north, the streams glided into the Arctic Ocean, and on the west, into the Atlantic ; to the south and east, the glaciers pushed their way across Denmark and the Baltic, and invaded the low-lying plains of North Europe. The thickness of the ice-sheet, beneath which the

land was buried, has been estimated at over 3,000 feet. In the valleys and fiords of Norway, the evidences of ice-action are unrivalled. Everywhere the rocks have been smoothed, scored and polished, while potholes have been excavated in the mountain slopes, and transported boulders strewn over the ground in profusion. Some of these boulders have been carried to a considerably greater elevation than that of the parent rock-mass. At Areskutan, for instance, blocks occur at a height of 4,500 feet, which could not have been derived from a source higher than 1,000 feet. Large areas of the lower-lying ground are covered with boulder-clay and glacial sands and gravels. In southern Norway, and on the eastern plains of Sweden are fine developments of kames and asar, long, ridge-like accumulations of material, of which the exact mode of origin has not been satisfactorily explained.

From Scandinavia the ice-sheet spread into north-west Russia and northern Germany, where the termination of the ice has been traced by erratics and moraines for miles across the country. Further south, the the mountains of the Vosges and Black Forest gave rise to independent glaciers.

In France, the former presence of glaciers among the mountains of the Auvergne, is indicated by the moraines and boulders which are now strewn over the ground. In the south of France, the great glacier of the Rhone, which covered all the low-lying ground

of Switzerland, and filled the hollow of the Lake of Geneva and all the higher tributaries of the Rhone, terminated 170 miles below its present limit, in a frontage extending from Bourg to the valley of the Isére—a distance of more than 100 miles. The other glaciers of the Alps were similarly enlarged. On the north, the glaciers coalesced to form a continuous belt of ice, which filled up Lake Constance and extended down the Rhine at least as far as the Black Forest. To the south, the glaciers pushed their way down on to the plains of Lombardy, where the moraines they left sometimes exceed 2,000 feet in height.

Most of the remaining mountain chains of Europe displayed glaciers of greater or less extent, even the Apuan Alps, in Tuscany, which do not exceed 6,700 feet in elevation. In the Pyrenees the glaciers of the Ice Age were immensely greater than those which now linger among the mountains. On the north they decended into the plains of France, the largest, that which filled the valley of the Garonne, being some forty-five miles in extent. On the Spanish side of the chain the glaciers were not of so great an extent.

In Asia, most of the more lofty mountain chains show signs of former glaciation. The glaciers of the Caucasus range now terminate at a height of between 7,000 and 8,000 feet above the sea, but during the Ice Age they appear to have extended to a considerably lower level. A small glacier still lingers on

Mount Ararat, but traces of the ice extend far below its present termination.

Of the great mountain chains of Central Asia our knowledge is still very imperfect, but in the ranges of the Himalayas there is abundant evidence of a great extension of the glaciers in the past. At the present time the lowest limit of the ice is about 10,000 feet above sea level; but in the valleys of Sikkim and Eastern Nepaul moraines have been noticed at elevations of between 7,000 and 8,000 feet. South of the Assam Valley the moraines extend down to 5,000 feet. In the Western Himalayas erratic boulders have been carried down to within 3,000 feet of the sea level, and in the Upper Punjab, even lower. No traces of recent glaciation have been discovered in central or southern India, but Messrs. Medlecott and Blanford have brought forward some interesting biological evidence pointing to the prevalence in former times of a cold period in the Peninsula. On some of the higher ranges in southern India, certain plants and animals are found, which also occur in the Himalayas, but do not occupy the intervening ground. These include some land-shells, a wild goat and a Himalayan rhododendron. It is inferred that these cold-loving species were at first driven from the Himalayas southwards, and then, as the temperature increased again, they retreated up the southern ranges and were thus, as it were, imprisoned.

In Africa, traces of a former glaciation

have been discovered among the Atlas Mountains of Morocco. Striated stones, polished rock-surfaces and other characteristic signs occur in the valleys at elevations of from 6,000 to 8,000 feet above sea level. Some of the terminal moraines are 800 or 900 feet in height. On Mount Kenya, in East Africa, immediately south of the Equator the glaciers now terminate at about 15,500 feet above the sea. But Dr. Gregory has shown that at one time they descended at least 5,400 lower than they do at present. This discovery has been supposed by some to indicate a lowering of temperature during the Glacial Period over the whole world, and not merely over one hemisphere; Dr. Gregory, however, is of opinion that the effects have been produced by a former greater elevation of Mount Kenya.

CHAPTER X

THE ICE AGE IN THE NEW WORLD.

On the continent of North America signs and traces of the Glacial Period occur on even a larger scale than they do in Europe. Scratched and polished surfaces, erratics, moraines, boulder-clays and other accumulations are found over areas many thousands of square miles in extent. In spite, however, of the vastness of the country to be examined, the labours of geologists, both in Canada and the United States, have enabled the general sequence of events to be made out.

Just as in Europe, there is evidence that in earlier Tertiary times a warm climate prevailed in North America, extending to regions well beyond the Artic Circle. During succeeding ages this, was gradually replaced by colder conditions, until at length, glaciers held undisputed possession of the country.

Here, also, considerable difference of opinion exists as to the parts played by land and sea-ice respectively; some authorities considering that nearly half the area of North America was covered by glaciers, while others maintain that a large proportion was submerged, and that the erratic boulders, which are strewn over the country, were dropped from floating masses of ice. It is, however,

generally admitted that two main centres can be recognised from which the ice radiated in all directions. One of these, the larger, occupied the plateau lying between Hudson Bay and the river St. Lawrence; the other was formed by the Cordilleras of western Canada.

At the present day the region north of the St. Lawrence is about 2,000 feet in height, but during the Glacial Period it probably stood considerably higher. The immense mass of ice, which streamed off these highlands and was further increased by ice coming from the regions to the north-west of Hudson Bay, has received the name of the "Great Laurentide Glacier." It spread over the whole of the eastern and central parts of Canada, and enveloped all the northern States of the Union, covering an area of some 3,000,000 square miles, and extending southwards to a point considerably nearer the Equator than the Pole. The limits of the ice have been traced by means of striated surfaces, erratics and deposits of drift, from the Atlantic across the continent to within forty miles of the Rocky Mountains. The boundary runs through Long Island across New Jersey and Pennsylvania almost as far as Lake Erie. Here it bends abruptly southwards through Ohio and Indiana and in Illinois reaches its lowest point in latitude 37° 35'. From this point the drift border sweeps through Missouri, Kansas, Nebraska, and Dakota to about latitude 47°, where it

turns westwards and runs across the plains of Montana. When about forty miles from the Rockies it again bends to the north, and runs through the Dominion of Canada as far as the mouth of the Mackenzie River. To the east, the ice of the Laurentide Glacier stretched away to the coast and probably far into the Atlantic. The northern border of the glacier has not yet been determined, but probably the ice extended over the mainland and most of the islands of the Arctic Ocean.

A remarkable fact in connection with the distribution of material by the Laurentide Glacier is the presence, well within the border, line, of an area some 10,000 square miles in extent, quiet free from drift and other signs of ice-action, though surrounded on all sides by well-glaciated country. This tract lies in the Upper Mississippi Valley, chiefly in Wisconsin, but partly also in Minnesota, North East Iowa, and Illinois. It is thus situated in the broad angle between Lake Superior and Lake Michigan, and the large valleys, in which these sheets of water lie, appear to have afforded an easy passage for the ice on either side of the driftless area, the two streams not uniting again until some distance further south.

The second great centre of dispersion of the ice was formed by the Cordilleras of British Columbia. The central névé appears to have accumulated on the plateau lying between the Rocky Mountains and the ranges nearer the coast. From the high ground, the

ice streamed northwards as far as the basin of the Upper Yukon, and southwards into Idaho, Montana and Washington. Westwards, the glaciers pushed their way down to the sea and filled up the channel between Vancouver's Island and the mainland ; while on the east they, to some extent, invaded the great plains, though not apparently reaching the margin of the Laurentide ice-sheet.

Further south, no extensive tracts of country seem to have been covered with ice, but all the loftier ranges gave rise to large glaciers. The valleys of the Yellowstone Park, the Uinta Mountains, and the Wahsatch range were filled with ice. To the west, glaciers were formed in the Sierra Nevadas as far south as the valley of the Yosemite.

It is somewhat remarkable that no signs of general glaciation are to be found over the great plains of Alaska. In some localities beds of ancient ice, probably formed from the snow-drifts which filled the valleys during glacial times, occur buried beneath accumulations of gravel or soil. This fossil ice, as it may be termed, is gradually wasting away, and in the process of melting, teeth and bones and even the soft parts of the mammoth and other animals are frequently exposed.

The various deposits of the glaciated areas are, in the main, similar to those of Europe, though often of greater extent and thickness. Till, or boulder-clay, is the most frequent member of the series. The thickness of the

sheets of boulder-clay varies between wide limits; over a large area the average may be put at 100 feet; but in some localities it exceeds 500 feet, and may even reach 1,000 feet or more. In the mountainous regions of the west, median, lateral and terminal moraines are often well-developed, but over the area covered by the Laurentide glacier, as a rule, terminal moraines only reach any considerable size. Some of these, however, are of enormous dimensions, extending for perhaps hundreds of miles across the country. One belt, in particular, sweeps in huge curves round the southern margin of the Great Lakes, across the basin of the Mississippi and on to the plains of Canada. Some of the moraines are smooth, broad, gently-curving swellings; others form belts of irregular mounds and bosses of material perhaps fifteen miles across.

On page 127 some account was given of those puzzling glacial accumulations known as kames, eskers and drumlins. All three of these types are well developed in America. Between eskers or asar, and kames no hard and fast line can be drawn, but the former appear to have been accumulated along the main drainage lines of the glacier, and consequently follow, more or less closely, the general trend of the valleys in the district in which they occur; the latter seem to have been formed along the edges of the ice-sheet, and usually run across the direction of movement of the ice.

Eskers are well developed in Maine, New Brunswick, and some other States of the Union, less frequently also in Canada. Some of the systems in Maine are very much branched and extended over a length of more than 100 miles. Kames are frequently associated with the terminal moraines lying to the south and west of the Great Lakes. According to Professor Chamberlain, kames were the products of vigorous ice-action, while eskers " seem to represent very inactive conditions of the ice."

Drumlins are well developed in the north-eastern States, especially in the neighbourhood of Boston, but perhaps, the finest examples occur in Wisconsin and Michigan. They are smooth, round-topped hills, formed of glacial material varying from 25 to 200 feet in height. In outline they are generally lenticular being about half as wide as they are long. The length rarely exceeds a mile, though occasionly it is as much as three or four miles. Geologists are not agreed as to the manner in which drumlins were produced.

Over a considerable area of North America, the drift material is capable of division into two or more sheets, and between these, in some localities, accumulations of twigs, leaves and other traces of vegetation have been discovered. In Eastern Iowa an old vegetal soil is interposed between two glacial formations. In Illinois and Indiana the layer of buried plants has received the popular name of " Noah's Barnyard."

Formerly it was supposed that all these beds of plant-remains were formed at the same time during a mild interglacial period, but it is now admitted that they do not all occur at the same position in the drift series, some of them probably being even pre-glacial. As in Europe, many authorities consider that the presence of vegetable débris does not call for belief in an interglacial period, but merely comparatively small recessions of the ice.

Associated with the boulder-clays in many places are deposits of sand, gravel and clay, frequently showing signs of stratification. Some of these were deposited in lakes, but others containing marine fossils were formed beneath the sea, and show that during part at least of the Glacial Period, some submergence must have occurred. The distance of the beds from the Atlantic renders any such scooping up of material from the sea-bottom, as was suggested in the case of the Welsh shelly deposits, very improbable.

The effects of the glaciers upon the drainage systems of the country were often very extensive. Rivers were diverted from their courses, and lakes, both permanent and temporary, were formed. Some of the latter, in particular, were of immense size.

In the more hilly regions of North America, large numbers of lakes and tarns were produced by the same process as that which operated in Europe. A glacier crossing the path of a stream filled up the channel with débris, and the water rose behind

the barrier until it found an exit through, perhaps, quite a different valley. One of the most interesting examples of this process is furnished by Lake Erie. Previous to the Glacial Period, the country covered by this great sheet of water was a broad, shallow valley, through which flowed a river of considerable size. The old course seems to have been through the lower part of the Grand River Valley in Canada into the western end of Lake Ontario. This channel becoming blocked up by glacial débris, the water rose behind the dam, forming the lake, and eventually finding an exit through the Niagara Valley, thus giving rise to the celebrated falls.

The determination of the geological period at which the falls of Niagara were brought into existence, has enabled an attempt to be made to estimate in years the length of time which has since elapsed, by observations of the rate of erosion of the river-gorge. This would fix, approximately, the date of the close of the Glacial Period. The length of the gorge which has been cut since the torrent first commenced its work, is between six and seven miles, and the estimates of the time which this represents vary from 7,000 up to 35,000 years. The problem, however, is by no means so simple as it appears, nor is the assumption that the rate of erosion has always been constant, fully justified; hence a large element of uncertainty is introduced into the calculations.

Another instance of a diverted river-course is afforded by the Mississippi, between the Minneapolis and Fort Snelling. The buried preglacial channel lies to the south-west and its site is marked by a chain of small lakes. The Falls of St. Anthony, which were formed when the river was first compelled to take its present course, have, since they commenced to flow, cut out a narrow gorge some seven miles in length.

Lakes which had but a temporary existence, being formed by the blocking of a river valley with ice, like the Märjelen See at the present day, or that which formerly occupied Glen Roy and the neighbouring valleys in Scotland, appear to have attained an immense size in America during the Glacial Period. The largest, named after the famous French geologist, Lake "Agassiz," was produced by the blocking of rivers which flowed northwards towards Hudson Bay and the Arctic Ocean. It appears to have covered an area of not less than 110,000 square miles, including Lakes Winnipeg, Winnipegosis, and large tracts of Manitoba, Minnesota, and Dakota, forming the basin of the Red River of the North. Some idea of the size of this vast sheet of water may be gained by recollecting that the total area of the existing great lakes, Superior, Michigan, Huron, Erie, and Ontario, is only some 95,000 square miles. The river which drained Lake Agassiz flowed southwards between Lake Traverse and Big Stone Lake into the

Minnesota River, which, in consequence, had at that time an enormously greater volume than it has at present. The effect of this is still seen in the great size of the Minnesota Valley, which is out of all proportion to the volume of the tiny stream which winds through it.

Another large lake was formed by the blocking of the Ohio River near Cincinnati by the ice. It occupied the valley of the river to beyond Pittsburg, covering parts of Kentucky, West Virginia, Ohio, and Pennsylvania.

In South America, signs of extensive glaciation have been described by Darwin and Agassiz in Tierra del Fuego and in Southern Patagonia and Chili. The valleys of the Andes, as far north as Aconcagua, appear to have been filled with ice. In Bolivia and also in Columbia, just north of the Equator, traces of ancient glaciers of large size have been discovered.

Comparatively little is known of the geology of large areas of Australia, but there does not seem to be any evidence of a general glaciation of the country. Dr. Lendenfelt succeeded in finding moraines, striated surfaces and other signs of ice-work on Mount Bogong, the highest mountain in Victoria. The glaciers which produced these would seem to have descended to about 3,000 feet above sea-level. In South Australia, boulder-strewn, glaciated surfaces have been traced, more or less continuously, for several miles, in St. Vincent's Gulf at a height of about forty

feet above sea-level. These effects may have been produced by glaciers coming from the neighbouring mountains, but it is equally probable that they should be attributed to sheets of drift-ice which were forced on to the land from the Antarctic Ocean. Moraines and erratics have been found in the valleys of Western Tasmania, which indicate that the glaciers, at one time, came down to within 2,000 feet of sea-level. The great central plateau would appear to have formed the gathering-ground of the snow, but the glaciers do not seem to have entrenched at all upon the valleys on the eastern side of the island.

In the mountains of New Zealand there are still many important glaciers, but they are small compared with those which once filled the valleys. Some of the ancient glaciers were seventy or eighty miles in length, and the moraines they left exceed 600 feet in height.

CHAPTER XI.

LIFE DURING THE GLACIAL PERIOD.

The fossil remains found in beds associated with glacial deposits, show that both plant and animal life existed during the Ice Age. In some places the plants form beds of peat or lignite, and these, as we saw in chapter ix., have been regarded as evidence of a warm, interglacial interval. They more probably, however, flourished during temporary retreats of the glaciers extending over the deposits the latter left behind them, and retreating to sheltered spots during the maximum extension of the ice. Bones of animals have been found associated with the beds of peat or lignite, and also sealed up beneath deposits on the floors of caves. These facts present no difficulty when we remember that in the far-north of to-day animal life may almost be described as abundant, while vegetation, though sparse, is by no means absent. There is no doubt, however, that great havoc was wrought among living creatures by the cold. A comparison of the fauna and flora which immediately succeeded the Glacial Period with the rich and varied life flourishing at the close of the Pliocene, times, shows that a large number of species of both plants and animals were exterminated.

In Britain examples of the association of beds formed of vegetable débris with glacial deposits are found chiefly in Scotland. At Slitrig Water, near Hawick, resting on a stiff boulder-clay ten to twenty feet thick, are some beds of gravelly sand and clay, which contain peaty layers formed apparently from the decayed rootlets of a kind of heath. On the top is another layer of glacial boulder-clay thirty to forty feet in thickness. At Hailes Quarry, two miles west of Edinburgh, a deposit of peat, which contains numerous fragments of birch-wood and wing-cases of beetles is found sandwiched in between two layers of boulder-clay. In making a cutting for a railway through glacial deposits near Neilston, in Renfrewshire, remains of vegetation were found which yielded abundant evidence of having been accumulated at the bottom of a lake, as probably was the case with most of the other peaty deposits. In addition to the seeds of numerous trees and flowering plants, water-fleas were found in great numbers, as well as desmids, diatoms, spiculae, and eggs of freshwater sponges, caddis-cases, and the jaws of a leech. At Redhall Quarry, near Edinburgh, Carmichael Water, in Lanarkshire, and other localities in Scotland, beds of vegetable origin have been found intercalated in glacial deposits.

Among the flora described from these beds are many familiar flowering plants, such as the buttercup, campion, cinquefoil, and bramble. Trees are represented by the oak,

alder, hazel, the nuts of which are in some places very abundant, and by the dwarf Arctic forms of the birch and willow. Reeds and grasses occur, but ferns do not seem to have been present. Among the water-plants are the bog-bean, mare's-tail and pond-weed. Nearly the whole of the plants are still natives of the south of Scotland. It is, however, a most striking fact that no modern plants of the Scottish Lowlands occur in the deposits, which have not a considerable range northwards. All the fossil species which have been found, range, at the present day, at least as far as the extreme north of Scotland, and many of them considerably further.

On the continent of Europe, plants intercalated in glacial deposits have been found in Sweden, Denmark, Germany, France, and the Alps. The lignites of Dürnten, in Switzerland, have, in particular, yielded a large number of forms, including pines, firs, yews, larches, oaks, sycamores, hazels, and mosses.

The fauna of the Glacial Period derives great interest from the fact that it comprises the immediate ancestors of many living forms, including man himself. Moreover, while the flora consists chiefly of familiar types, differing but little from those of the present day, the animal life includes a number of strange, extinct forms. Additional interest is given to the fauna of the glacial period by the evidence it affords of a remarkable mingling of species, the descendants of which now inhabit widely-sundered portions of the globe. Living

in Europe and North America, during that epoch, either simultaneously, or separated by only brief intervals of time, perhaps even merely seasonal, were animals, some of which are now confined to Equatorial regions, while others live only within the Polar Circle. At the beginning of the period the number and variety of the animals were greater than at at the present day, but many forms failed to survive the cold, while early hunters, armed with implements of flint, doubtless hastened the extermination of others.

Bones and other remains of the animals have been found in deposits of peat, river-terraces, old lake-bottoms, surface accumulations, caverns, and less frequently in the mud cliffs of Alaska and Siberia.

The deposits of peat described above as associated in some places with glacial beds have yielded the bones of a considerable number of animals; but more have been obtained from the extensive peat-mosses which belong chiefly to later glacial times, when vegetation had again spread over the land in considerable amount. The larger animals which ventured upon the treacherous, marshy surface of the bog were particularly of liable to be engulfed; hence the bones deer and oxen are common fossils in the peats of Europe. River-terraces are found along the sides of valleys often as much as 80 or 100 feet above the present level of the stream. They were built up at first by the deposits laid down on the banks by successive floods,

at a time when the river flowed at a higher level that it does at present. But as the channel became gradually worn away, and the level of the river bed lowered, the terraces were ultimately left sufficiently high to be out of the reach of inundations. By estimating the present rate of erosion of a river bed and the height of the terrace above the level of the stream, attempts have been made to determine the length of time which has elapsed since the formation of a given terrace. The assumption, however, that erosion has proceeded at the same rate in the past as it does at present, is not fully justified. River-terraces contain the remains of numerous mammalia which were swept away during the floods and covered over with sediment.

But perhaps the most important instances of the preservation of animal remains are those which are afforded by the deposits forming the floors of many caves. Formerly these caverns were the haunts of cave-loving animals, such as the hyæna, cave-lion and cave-bear; but besides their remains, the gnawed and splintered bones of their prey which they dragged into their dens, have been found in abundance. Other animals crept in to die. Perhaps, at some period, the cave was occupied by men, who strewed on the floor the charred bones of the animals they killed in the chase. Thus it happens that the remains of a very large number of species are found in ossiferous caverns. In caves formed in limestone, a thick deposit of calcareous material has often

occurred since they were occupied. Drops of water containing lime in solution percolate through the roof, and as they evaporate give rise to the long pendants and delicate columns known as stalactites, which lend such beauty to many caverns. Some of the water falls to the ground, and there forms a layer which gradually surrounds any bones or implements lying on the floor of the cave, and thus ensures their preservation. Sometimes a cave has been the haunt of successive generations of animals, and the remains of each set have been sealed up and kept separate from those which followed. These are the most valuable to the geologist. Others have been invaded by floods, and their contents, so thoroughly commingled, that no succession can be made out. In a few the order has been disturbed by man, generally for purposes of interment.

Some of the caves in which animal remains have been discovered are now of classic interest; as for instance, Kent's Hole, near Torquay, in Devonshire, one of the first in which flint implements were found associated with the bones of the mammoth and other extinct mammalia. Numerous caverns occur in the limestones of North Wales and the north-west of England, beneath the floors of which the bones of many species of animals have been found. Dr. Henry Hicks, who explored several of these caves, has recently summarised the results. He points out that the geographical features of the region were, in all probability, eminently suited to the

presence of large herds of mammalia. The general elevation of the land in this direction appears to have been greater than it is at present, resulting in the formation of broad plains between what are now the coasts of England and Wales, and Ireland. These extensive feeding grounds were nearly surrounded by the mountains of the south of Scotland, Cumberland, Wales, and north-east Ireland; but northern forms were able to reach them across Cheshire and the lowlands of England, while southern forms travelled up the plains on the west coast of Wales. "When the higher caverns were first occupied by hyænas, it is probable that there was comparatively little ice or snow on the mountains, and many of the animals which lived in the valleys and on the plains extending from them were southern types. Gradually, however, as the cold increased, northern forms appeared on the scene, and a co-mingling of the two groups took place." *

On the continent of Europe, the most important discoveries of remains have been made in caves in the limestone precipices of the valley of the Meuse, near Liege, in the valley of the Neander, a small tributary of the Rhine, and in Southern France. In some of these caves the skulls and other bones of men, apparently belonging to a primitive type, have been found.

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* *Quart. Journ. Geol. Soc.*, May 2nd, 1898. Anniversary Address of the President.

Perhaps, the most striking instances of the preservation of animal remains are afforded by the carcases of the mammoth and rhinoceros, which are, from time to time, found embedded in the frozen mud-cliffs of Siberia. Although many thousands of years must have elapsed since they were entombed, the flesh has, in some cases, been so well preserved that the natives have taken it to feed their dogs. In the cavities of the teeth were found minute fragments of coniferous leaves and shoots, and other traces of the vegetation upon which these animals lived.

The extensive and varied animal life of the Glacial Period, the remains of which have been recovered from the different sources detailed above, admits of division into three main groups; a group comprising northern forms, or forms the descendants of which occupy cold regions; a southern or warm climate group; and a group of animals which now inhabit temperate countries. In the case of extinct species, however, it is not always possible to tell with certainty to which group they should be assigned; and it must be observed that even species still in existence may, in past times, have been able to live under conditions of climate differing from those which now seem to be essential.

One of the most numerous of the northern types was the woolly-haired mammoth (*elephas primigenius*). (Fig. 28), an animal already mentioned as one of those found in the frozen soil of Siberia Its weight was

about twice that of a modern elephant and its height one-third greater. It was furnished

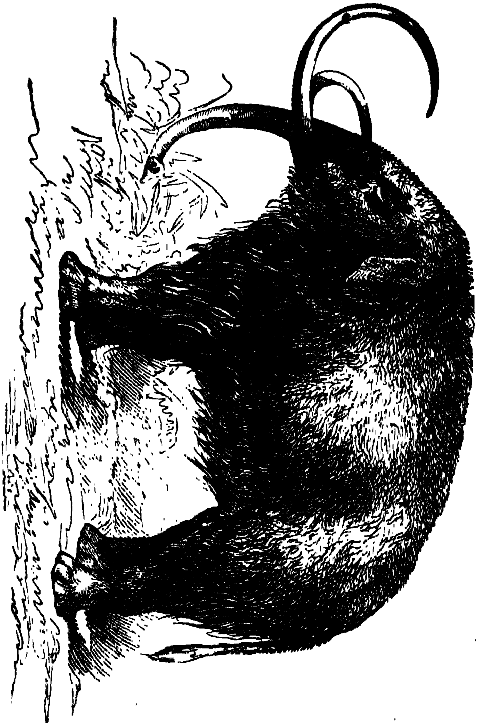

FIG 28.—THE MAMMOTH (*Elephas Primigenius*).
(KAYSER-LAKE. TEXT-BOOK OF COMPARATIVE GEOLOGY.)

with tusks which sometimes attained a length of more than twelve feet, and were curved backwards almost into the form of a circle.

The portions of skin which were found on the frozen carcases show that the mammoth was covered with a thick coating of long, black hair, at the base of which was a dense layer of reddish-brown wool. But even if the frozen specimens had not been discovered, we should still have known of the woolly covering of the mammoth from the rude sketches of him which have been found carved on fragments of his own tusks by his early hunters in Europe (Fig. 32.) Although the nearest modern allies, the Indian and the African elephants, now only inhabit warm countries, the northern character of the mammoth is indicated by his skin which evidently served as a protection against the rigours of a cold climate as well as by his distribution, fossil remains not occurring south of a line drawn through the Pyrenees, the Alps, the northern shores of the Caspian Sea, Lake Baikal, and Kamschatka. Vast herds of these animals must have roamed over the plains of northern Europe and America during the Glacial Period, and their tusks were formerly so abundant in Siberia as to give rise to a considerable trade in ivory.

Another northern form, the carcases of which have not infrequently been washed out of the frozen river-deposits on the banks of the Yenisei and Lena, in Siberia, was the woolly rhinoceros *(rhinoceros tichorinus)*. It appears to have had much the same distribution as the mammoth, and like it, was provided with a thick coat of woolly hair.

The front horn was of great size; and the skin does not seem to have been thrown into folds as is the case with the living Indian species. Other forms now confined to the Arctic regions, were the glutton, the musk-sheep, the lemming, the marmot, the Alpine hare, the snowy-owl, the Artic fox, the Polar bear, and the reindeer. The last seems to have been extraordinarily abundant in the south of France.

Among the animals of a more southerly aspect were the lion, the leopard, the African elephant and the lynx ; while in the caves were the hyæna and huge cave-bear ; and in the rivers, herds of hippopotami, which Sir William Dawson has suggested, may have been protected from the cold by a layer of fat or blubber beneath the skin, just as the walrus is at the present day. But, perhaps, the most remarkable form was the terrible *machairodus*, or sabre-toothed tiger, which lingered on from the warm Miocene and early Pliocene time and became extinct during the Glacial Period. In all probability this creature was the fiercest and most powerful animal that has ever appeared on the globe. It exceeded the modern tiger in size and strength, and was provided with a pair of enormous canine teeth, which projected right over the lower jaw, sometimes attaining a length of ten inches. (Fig. 29.) The mastodon was another form which appeared first as far back as the Miocene epoch. It does not seem to have existed in Europe after Tertiary

times, but in America it survived until nearly the close of the Glacial Period: The mastodon formed one of the *proboscidea*, or elephant group, but differed from the mammoth and from living forms chiefly in the character of its teeth. Its height was about eleven feet and length seventeen feet. The tusks, which were much less curved than those of the

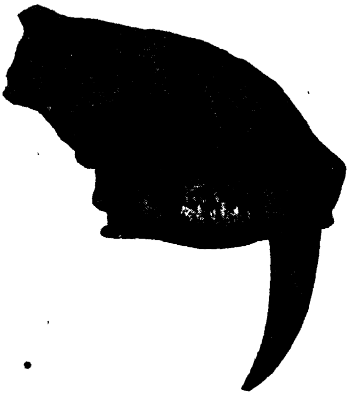

FIG. 29.—SKULL OF THE MACHAIRODUS OR "SABRE-TOOTHED" TIGER.

mammoth, were, including the part inserted within the sockets, about twelve feet long. A perfect skeleton was found by Dr. Warren, in a marsh near Newburgh, New York, "with its legs bent under the body and the head thrown up, evidently in the very position in which it mired. The teeth were

still filled with the half-chewed remnants of its food, which consisted of twigs of spruce, fir and other trees; and within the ribs, in the place where the stomach had been, a large quantity of similar material was found." *

Belonging to the temperate group were such animals as the horse, brown bear, grizzly bear, beaver, wild boar, lion, wild cat and several species of deer, including a large form known as the "great Irish elk." Skeletons of this animal, some of which showed a spread of more than eleven feet between the antlers, have been found in considerable numbers beneath peat-bogs in Ireland and other parts of the British Islands, as well as on the Continent. Bones of the horse have been frequently found associated with human remains, but under circumstances which, as Professor G. F. Wright has pointed out, lead to the belief that his chief use to early man was as an article of food and not as a domesticated animal.

The strange intermixture of northern and southern forms of life, which the cave-deposits and river-gravels contain, presents a puzzling problem to the geologist. One explanation, which does not, however, now meet with much support, assumed that the climate of Europe at the time the animals lived was liable to very marked seasonal changes; that the winters were extremely cold, and the summers correspondingly warm and genial.

* "Le Conte's Geology." Edition 1891.

The annual migrations of the fauna were in consequence very great; during the summer months, the lion, the hippopotamus and the elephant occupied the country, but on the approach of winter they migrated southwards to warmer regions; while the mammoth, the woolly rhinoceros, and the reindeer, travelled down from the north, and took possession until the following spring, when they once more retreated northwards before the southern fauna. A comparatively small elevation would provide the necessary land-bridge by means of which animals could pass between England and the Continent. Siberia was considered to present an instance of such migration at the present day. The annual range of temperature there is enormous; at Yakutsk, for example, in latitude 62° 5′ N., it extends from 62° F. in summer to 43° F. in winter, a difference of 105 degrees. Professor James Geikie has pointed out that, during the winter months, the reindeer roams so far south as to occasionally fall a prey to the tiger. In Alaska, an equally great migration takes place every year. There are, however, many strong arguments against this theory. The abundance of the animal-remains, especially of the hyænas, shows that they were permanent occupants and not merely summer visitors. Many of the animals, as for instance, the lion, the elephant, the hyæna, and the hippopotamus, are not migratory forms. While the wanderings demanded of the animals are out of all pro-

portion to anything which takes place on the globe at the present day, even the extensive migrations previously mentioned, being only from a cold to a temperate zone.

Professor James Geikie, in the last edition of "The Great Ice Age," came to the conclusion that the Glacial Period was interrupted by five distinct interglacial epochs, during which the ice retreated and a mild climate prevailed. At each of these intervals, but more especially during the earlier ones, animals migrated into Europe from the south, and remained until driven back by the ensuing period of cold. Other authorities, however, have held that the phenomena in question can be explained by assuming temporary diminutions in the size and extent of the glaciers, not sufficiently great to be dignified by the term "interglacial periods." During the milder periods, the southern animals encroached upon the northern, but when the cold again increased the Arctic forms were in their turn driven southwards. Many of the southern forms, however, probably only lived in Europe during the earlier stages of the Glacial Period, and when once driven away by the cold never returned to their old haunts.

We have still to consider the most interesting traces of life which have been found in deposits formed during the Ice Age, viz., those of man himself. Both the quarter of the globe, and the period of the geological record in which man first

appeared, are unknown; but the discovery of his bones and implements in deposits of Pleistocene age has enabled geologists to partially draw back the veil which hides his early life in Europe and America.

The relics of primitive man have been obtained chiefly from the same two sources as the bones of the mammalia of the Glacial Period, namely old river-gravels and cave deposits. Implements of flint were found in river-terraces in the valley of the Somme, near Abbeville, northern France, in 1841; but it was not until several years afterwards that they were definitely admitted to be of human workmanship. These terraces were ninety feet above the present level of the river, and contained bones and teeth of the mammoth and other extinct animals; hence the discovery in them of traces of man, pointed to a far higher antiquity of the human race than had hitherto been supposed. Further research brought to light thousands of implements of flint in the terraces of the Somme, and since that date they have been discovered in river-deposits over the greater part of the globe, probably dropped by their early users into the water while fishing, or hunting wild fowl on the banks. In caves also, the implements, and much less frequently, the bones, of primitive man have been discovered associated with the remains of the animals of the Glacial Epoch. Holes in the rocks formed his earliest shelters before the art of building huts, or erecting pile

dwellings on the lakes, had been acquired; and this fact has sometimes earned for him the title of the "cave-man."

The pre-historic existence of mankind has been divided into four great periods, according to the types of the implements which were successively employed. During the earliest, the Palæolithic or Old Stone Age, the implements man fashioned were of flint, rude in form and merely chipped into shape; in the Neolithic or New Stone Age, he had advanced sufficiently to polish his tools, and often to give them a high degree of finish. The succeeding periods, the Bronze Age and the Iron Age, are characterised by the use of metals. Much interesting information about these four stages in the early history of the human race will be found in "The Story of Primitive Man." * It was only the man of the Old Stone Age who was coeval with the Glacial Period, and in this volume we must confine ourselves to him and to his relations with his surroundings. When his Neolithic successor appeared, the period of cold had almost passed away, and many of the large mammalia had become extinct.

The relics of the men who inhabited Europe during the Glacial Period consist chiefly of implements, bones being only exceptionally found. Most of the implements are of flint (Fig. 30), and vary in shape according to the

* By Edward Clodd. "The Library of Useful Stories" Series.

purpose for which they were employed. They comprise simple flakes which were used for knives, arrowheads, and scrapers for

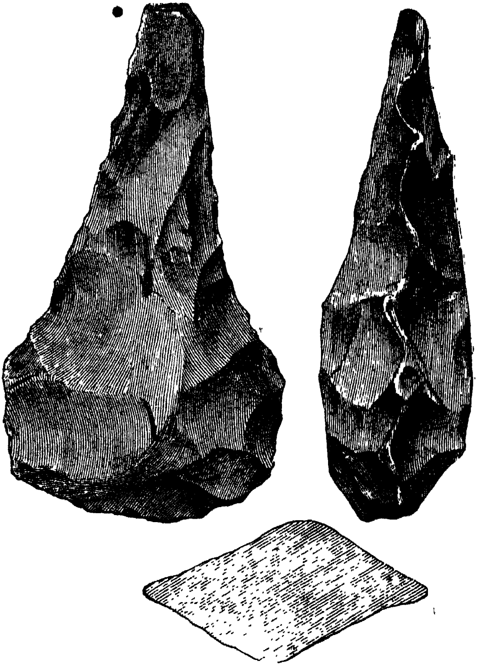

FIG. 30.—PALÆOLITHIC FLINT IMPLEMENT, EALING DEAN.

cleaning the skins of animals killed in the chase; and larger, pointed and oval pieces employed for spearheads, axes, and hammers.

The central core of a mass of flint, left after pieces have been clipped off it from every side, has also, not infrequently, been found on the old cave floors. In some localities, as for instance, Hoxne, in Suffolk, the number of worked flints discovered has been so great as to give rise to the belief that they mark the site of an old manufactory of implements. Stones sharpened and bound with thongs to wooden handles, are still used by certain savage tribes for making axes and for other purposes, and these have thrown light upon the manner in which the Palæolithic man

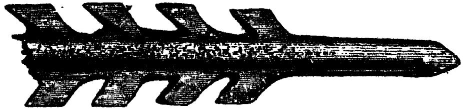

FIG. 31.—HARPOON HEAD, KENT'S CAVERN

employed his flints. The North Americans Indian, before he became acquainted with the use of fire-arms, employed arrows tipped with thin flints, which easily pierced the tough hide of a buffalo. But flint was not the only material from which implements were made. In the south of France, antlers of the reindeer were trimmed into the shape of picks and hammers; while barbed arrow-heads, harpoon-heads, and needles were constructed from pieces of bone or horn (Fig. 31). In Kent's Hole, a bone needle was found with an eye of a size to admit small pack-thread, as well as several harpoon-heads

of horn or bone. Thread was made from the sinews and intestines of animals. That the cave-men had learnt the art of obtaining

FIG. 32.—FIGURE OF THE MAMMOTH, ENGRAVED ON A FRAGMENT OF A TUSK BY PALÆOLITHIC MAN. LA MADELAINE, FRANCE.

fire, is shown by the occasional presence, among their remains, of ashes and bones more or less charred. But perhaps the most interesting relics of this early race are the

sketches and carvings, some executed with considerable vigour, which have been found incised on fragments of bone and ivory. The caves of the Dordogne, in the south of France, have in particular yielded a number of these traces of a primitive art. The figure of the mammoth carved on a fragment of his tusk has already been referred to; on others are scratched scenes representing the hunting of reindeer, horses, and oxen.

It is a somewhat remarkable fact that, although his implements are found in such great abundance, the actual bones of the Palæolithic man have rarely been discovered. Several influences seem to have combined to bring about this result. In all probability man existed in far smaller numbers than the other animals, and hence his remains would not so frequently be liable to be preserved. Another and greater cause was the comparative smallness of his bones. While the large bones of the mammoth and rhinoceros would tend to remain, those of man would be easily destroyed by the hyænas and other cave animals; or if buried in peat or alluvum would be readily disintegrated. Again, the absence of his bones from the river-gravels is doubtless partially the result of his own intelligence. As Sir Charles Lyell pointed out, he was probably "too wary and sagacious to be often surprised and drowned by floods, which swept away many an incautious elephant or rhinoceros, horse and ox."

But the few skulls and portions of skeletons

which have been found, possess a singular interest, as they enable us to compare the men of the Palæolithic period with their modern descendants. In 1857, a skull was found in a limestone quarry at Neanderthal, near Dusseldorf, in Germany, which attracted much attention in the scientific world, on account of its ape-like characters. The capacity of the skull was about 75 cubic inches, which is consideraby less than that of the European skull, but not less than that of the Hottentot or Polynesian, while it is far above the skull capacity of even the highest apes. The ridges above the eyes are enormously developed, the forehead is low and retreating, and the back part of the skull is of a low type. In the vicinity of Liege, in Belgium, several human crania have been found. One of these, the 'Engis skull,' was of the ordinary Caucasian type, but was found associated with the bones of the mammoth, woolly rhinoceros, and other extinct animals, at a depth of about five feet beneath the floor of a cave. In the commune of Spy, in 1886, two incomplete skeletons were found, together with mammalian remains, beneath a thick deposit of material. Both of these were of a low type, the orbital ridges being prominent, the foreheads low and retreating, the lower jaws heavy, and the teeth large. A skull which was found at Canstadt, in 1700, but not examined till 135 years later, exhibited similar characters. A few others have been found in different parts of Europe. These

various discoveries indicate that the man who lived in Europe during the Glacial Period and hunted the mammoth and rhinoceros, was of a primitive type, probably not unlike the Bushmen or Fuegians of to-day.

In America, distinct proofs of the existence of man, at least during the later stages of the Glacial Period, were first discovered in 1875 by Dr. C. C. Abbott, at Trenton, in New Jersey. From a terrace, deposited in all probability by the great volumes of water which flowed from the melting glaciers, he obtained numerous Palæolithic implements, some of them lying at a considerable depth below the surface. Flint is almost completely absent from the district, and the implements are, in consequence, made of the next best material obtainable, a kind of clay-slate; but in other respects they resemble those found in the European caves and drifts. In 1882, attention was drawn by Professor G. F. Wright, to the probability of finding human traces in the glacial terraces of Ohio and other states, and during succeeding years these expectations were realised by the discovery of flint implements in several parts of Ohio, in Indiana and in Minnesota. The animal-remains most frequently associated with the implements are the bones of the mastodon, but those of the walrus, reindeer, bison, and musk-sheep, also occur.

As in Europe, human bones are extremely rare, and indeed, from the eastern States are unknown; but in 1866, a skull was discovered

in Calaveras County, on the Pacific coast, which was believed by Professor Whitney to be of very great antiquity, though some doubt has been expressed as to its age. The "Calaveras skull," as it is termed, was said to have been found beneath a bed of lava; and that a long interval of time has elapsed since this was poured out, is shown by the fact that the lava now forms a prominent ridge standing above the general level of the ground, the softer rocks, composing the sides of the valley down which it originally streamed, having been worn away by erosive agencies. From the deep auriferous gravels in the vicinity, stone mortars, spear-heads, and other implements were obtained.

The antiquity of the human race furnishes a problem which is still far from being solved, but the various discoveries mentioned in the preceding pages have contributed in no small degree to throw light upon it. We have seen that there is abundant evidence of man's presence in Europe during part at least of the Glacial Period. But is it not possible to make this statement a little more definite? Was he already present when the snows first began to accumulate among the mountains, and glaciers to creep down the hillsides? Did he migrate into Europe during the climax of the Arctic conditions; or did he make his appearance in the later stages when the period of cold was waning? Dr. Henry Hicks has recently attempted to answer these questions. From an examination and com-

parison of the evidence afforded by numerous caves, chiefly in north and west of England and Wales, he has come to the conclusion that man existed in pre-glacial times, or at least, "so early in the glacial period that there could not have been at the time any considerable amount of snow on the neighbouring mountains, or glaciers, even in the higher valleys."*

The mere fact of the association of human remains with the bones of many of the extinct mammalia, carries the date of man's presence in Europe pretty far back in the Glacial Period. Some of these animals are represented by bones found only at the base or in the lower parts of the drift, and in all probability, they were forms which existed in Europe only during the earlier stages of the Ice Age, migrating southwards when the conditions became too severe, and never revisiting their old haunts. But Dr. Henry Hicks and other cave explorers have obtained more conclusive evidence of man's antiquity from the character of the deposits which have been formed above his implements, since the latter were left on the floors of the caves he occupied. Many of the caves of Wales, subsequent to their occupation by man, have been invaded by floods, and the retreating water has left behind a layer of sandy gravel and clay containing pebbles and fragments of rock

* *Quart. Journ. Geol. Soc.*, May, 1898. Anniversary Address of the President.

swept in from outside. We have already seen that during the Glacial Period large areas of North Wales were covered over with drift deposits containing stones derived from neighbouring and distant localities. A flood-gravel, laid down before the Glacial Period, would in consequence contain only material of purely local origin, or such as might have been carried down by the river; but one which was the result of an inundation occurring after the drift had been spread over the country, would be liable to contain stones derived from distant sources. The Ffynnon Beuno Cave, in the Vale of Clwyd, is an instance of one in which it has been possible to discriminate between the various flood-deposits it contains. Where the succession is undisturbed, the lowest stratum, which contains implements of Palæolithic man and bones of extinct mammalia "consists entirely of such local material as would be left by a stream or flood-water when the cavern was being formed. In this there was not a fragment of any foreign material, such as is now abundant in the field above, on the slopes of the valley and about the entrance of the cavern."* Overlying this deposit was a floor of stalagmite, upon which rested a sandy clay containing fragments of material derived from other areas, and resembling those in the glacial drift outside the cavern.

Though not strictly speaking within the

* Op. cit.

subject of this volume, it is desirable, for the sake of completeness, to briefly mention the facts which have been regarded by some as evidence of man's existence in periods earlier than that described above. At Thenay, in France, and on the banks of the Tagus, in Portugal, deposits formed so far back in the geological record as the Miocene period have yielded flints which were said to have been artificially chipped. The indications of human workmanship in these cases are, however, extremely doubtful. A slightly greater degree of probability attaches to the suggested traces of the hand of man, exhibited by certain flints found on the chalk-plateau of western Kent. The gravels in which the flints were found are older than the existing river-system, and consequently older than the gravels of those rivers which contain Palæolithic implements of the ordinary type. The chipping is of so rude and primitive a character that it has been ascribed to a race less advanced than the Palæolithic people. Many authorities, however, consider that the plateau "implements" show nothing more than fractures produced by the ordinary processes of nature.

In 1891-92, some bones were found by Dr. Eugene Dubois, in the island of Java, which apparently were those of a creature distinctly intermediate in character between man and the higher apes. They consisted of the upper part of a skull, two molar teeth, and a left femur, and were associated with the remains of numerous extinct mammalia.

The supra-orbital ridges were very prominent, and the cranial vault was depressed. The teeth presented marked ape-like characters. Owing to the fact that the femur was separated from the other bones by a distance of fifteen meters, some doubt exists as to whether they were all portions of the same skeleton. Dr. Dubois, however, considers that probably the separation was effected before the bones were covered up, during the process of disintegration of the flesh. The presence of crocodiles is indicated by their remains in the beds, and they may well have torn away the limb. On many of the mammalian bones, the impressions of the teeth of crocodiles can be discerned. The beds in which these interesting discoveries were made appear to be of late Plioicene age, but their exact position is not fully ascertained.

The evidence, therefore, at present in our possession, of man's existence previous to the Glacial Epoch is scanty and uncertain. Nevertheless, the high stage of developement, which his implements prove him to have reached at the beginning of that period, renders it extremely probable that he had already been long upon the surface of the globe. At present only a small proportion of the land area has been searched for the traces of primitive man; we may, therefore, confidently look to future discovery to carry the date of his appearance upon the earth further back into the past than we are able to do at present.

CHAPTER XII.

THE CAUSE OF THE ICE AGE.

THE cause of the Ice Age has been investigated by both geologists and astronomers, and the various explanations they have given may, in consequence, be divided into two groups, viz., those which are based upon changes occurring outside the earth; and those which have for their foundation alterations in the physical features of the crust of the globe itself. Many of the complex movements of the bodies which form the solar system are undergoing periodic variations, some requiring for completion an enormous interval of time. Astronomers have shown that during certain phases of these changes the amount of heat received from the sun, or its distribution upon the two hemispheres, might have been sufficiently different from that which now obtains as to give rise to an Ice Age. Geological evidence, on the other hand, has shown that the relative positions of the land and sea are slowly, but constantly, altering, and that, at one time, a tract of land may have had but a slight elevation above sea-level, at another, perhaps, it projected far above the snow-lines The great ocean-currents also have not always flowed along their present paths. Changes such as these

must have had a profound influence on climate, perhaps lowering the temperature sufficiently to explain the phenomena of the Glacial Period.

Let us examine the various explanations a little more in detail.

Taking first those which depend upon changes in the solar system, we find that certain of them, though more or less conceivable, do not admit of much discussion, as there is little or no evidence in support of them. It has been suggested, for instance, that the amount of heat emitted by the sun during past ages has varied; that during the early Tertiary period the sun was blazing with great brilliancy, but that it gradually waned during succeeding ages until the low temperature of the Glacial Epoch was produced. A fresh accession of heat, perhaps brought about by the falling of a quantity of meteoric material into the sun, raised the temperature to that which now prevails. Stars which display remarkable changes in brilliancy have certainly been detected in the heavens. In some of these, known as *variable stars*, a periodic increase and diminution in the light appears to take place; others have blazed forth strongly for a short time, and then have waned or completely disappeared. Such a one, for instance, was described by the astronomer Tycho, in the year 1572. It appeared in the constellation Cassiopeia, and attained such brilliancy that it could be seen by the naked eye in full daylight. It

gradually waned from the time of its first appearance, and at the end of sixteen months had completely disappeared. It does not seem probable that similar changes could have occurred in the sun without producing other effects than those we have evidence of; moreover, the extremely gradual nature of the climatic changes negatives the suggestion of any sudden increase or decrease in the amount of the sun's heat.

Another suggestion, which meets with but little support, is that the whole solar system, of which the earth forms a unit, has in past times travelled through regions of space of varying temperatures, a warm tract giving rise to a mild and genial climate, even within the Polar Circles, while a cold region of space was responsible for the Arctic conditions which prevailed during the Ice Age.

A change in the position of the earth's axis of rotation has also been suggested. Such a shifting would cause the Poles to take up positions on the surface of the globe other than those they now occupy. A similar effect would be produced if the solid crust or shell of the globe were to slide bodily round the semi-fluid interior. Neither of these views seems likely to be the correct one. Physicists have pointed out that the flattening of the earth at the Poles and the bulging out at the Equator produce a very high degree of stability, and necessitate the existence of enormous forces in order to produce even a small change in the position of the axis of rotation.

Geologists, moreover, have shown that the fossil evidence points to a zonal arrangement of life round the Poles in the past, like that which prevails at the present day.

A theory first, brought forward by the late Dr. Croll, and subsequently upheld and developed by Professor James Geikie and Sir Robert Ball, is deserving of far more attention than these unsupported suggestions. It depends upon certain slow changes which take place in the amount of inclination of the axis of the earth to the plane of its orbit, and in the shape of the yearly path which the earth pursues round the sun. A complete discussion of the theory is not possible in these pages, but an outline of its chief features may be given.

The axis of the earth is not quite perpendicular to the plane of its orbit (that is its path round the sun), but is inclined at a small angle with the vertical, as shown in Fig. 33, where a card held at right angles to the page, with its edge along the line **A B**, would represent the plane of the orbit. The result is that each of the Northern and Southern Hemispheres is for part of the year turned slightly towards the sun, and for the remaining part turned slightly away from it. The difference which we recognise between the temperatures of the seasons is thus produced. But the inclination of the axis to the orbit is not quite constant; each year it increases or decreases by a small amount, so that starting from the position of maximum inclination on one side, the axis slowly swings back, through

the perpendicular, until it makes an equal angle on the other side, and then slowly returns to its former position. A single oscillation from one side to the other requires

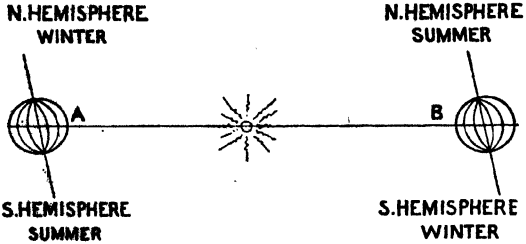

FIG. 33.—DIAGRAM SHOWING THE INCLINATION OF THE AXIS OF ROTATION OF THE EARTH TO THE PLANE OF ITS ORBIT

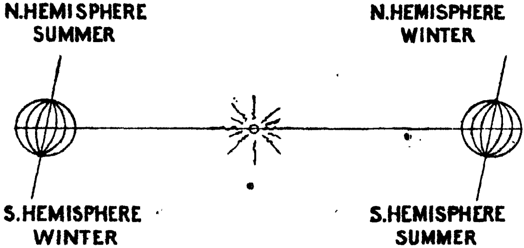

FIG. 34.—THE SAME, AFTER AN INTERVAL OF 10,500 YEARS.

about 10,500 years for completion, and at the beginning and end of that interval the positions are completely reversed, as shown in Figs. 33 and 34.

The second change we have to consider takes place in the form of the path of the earth round the sun. This is not a true circle, but an ellipse, in which the sun occupies the position of one of two points situated on either side of the centre, known as the foci. It follows that when at the part of its course, indicated by the letter **A** in fig. 35 (when it is said to be in Aphelion), the earth is at a considerably greater distance from the sun than when in the position **B** (Perihelion).

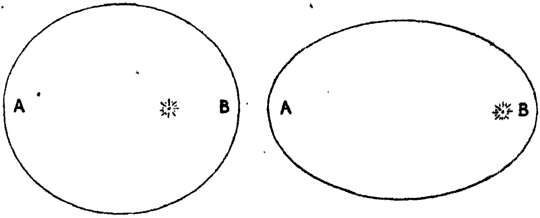

FIG. 35.—DIAGRAM SHOWING THE VARIATION IN FORM OF THE ORBIT OF THE EARTH.

But the shape of the orbit, like the inclination of the axis, is also subject to variation, being at one time nearly circular, then gradually becoming more markedly elliptical, and then again becoming more or less circular. The difference between the two shapes of the orbit is indicated in fig. 35, though in each diagram the deviation from the circle has been exaggerated. The interval of time during which the orbit is most flattened and elongated (as in the right hand diagram in Fig. 35), is known as a period of *maximum*

eccentricity. These changes in the shape of the orbit extend over a vastly longer interval of time than the alteration in the direction of the axis of rotation, and do not occur at such regular intervals. Dr. Croll calculated that a period of maximum eccentricity occurred about 200,000 years ago and came to an end about 80,000 years ago; another took place about 750,000 years back; another 850,000, another 2,500,000, and another 2,600,000. It follows that a reversal in the direction of the axis must occur many times while one complete change in the eccentricity is taking place.

Consider now a period of maximum eccentricity. At the point **A** in Fig. 35, where the earth is at the greatest distance from the sun, or in Aphelion, it is no less than 14,000,000 miles farther from that body than when it is at the shortest distance or in Perihelion, **B**. Consequently the amount of heat received from the sun in the Perihelion position is considerably greater than the amount received in Aphelion. If the position of the axis is such that winter, say, in the Northern Hemisphere, occurs when the earth is in the position **A**, the temperature is still further lowered owing to the great distance of the earth from the sun; moreover, the cold season is of some thirty-three days longer duration than the summer. Under these circumstances, it is argued that the amount of snow and ice produced during the long cold winter would be greater than could be melted

during the short, hot summer. The ice would, in consequence, slowly accumulate, until at length the conditions of the Glacial Period were brought about. After an interval of some 10,500 years the position of the axis has become reversed, though only a small change in the shape of the orbit has occurred during that interval. The influences which tend to produce heat and cold are now acting in opposition to each other. Summer occurs when the earth is at the greatest distance from the sun, winter when it is at the least, hence the former season is cooler, and the latter warmer and milder than under other circumstances. A partial neutralisation of this sort occurs in the Northern Hemisphere at the present day, for during the winter we are actually some 3,000,000 miles nearer the sun than in the summer. In the Southern Hemisphere, on the contrary, the difference between the heat of summer and the cold of winter is accentuated, but the eccentricity at present is not sufficient to give rise to a Glacial Period.

It will be seen from Figs. 33 and 34 that the condition of affairs, at any period in the Northern Hemisphere, is exactly the reverse of the conditions in the Southern Hemisphere. Thus, when in the northern half of the globe the year is divided in a long, cold winter and a short, hot summer, the Southern Hemisphere is characterised by a fairly constant climate throughout the year, neither the cold of winter nor the heat of summer being

excessive. In the course of time, the reversal of the direction of the earth's axis causes the mild, even climate to prevail in the Northern Hemisphere, while now the southern portion of the globe exhibits the condition of a great range of temperature between summer and winter. From this it follows that there should have been alternately warm and cold intervals in each hemisphere during the period of maximum eccentricity.

It must be carefully noticed that even when the eccentricity is at its maximum, there is no diminution in the *total* amount of heat received by the glaciated Hemisphere during the year. It is the unequal distribution of the heat which is regarded as having brought about the phenomena of the Ice Age. Enormous quantities of water were evaporated from the surface of the ocean in Equatorial regions, and were deposited as snow over the colder areas to the north. In consequence, "the sunbeams, in the brief and fiercely hot summer of the Glacial Period failed to melt as much ice as had been accumulated during the preceding winter. Thus it was that the ice-sheet was permitted to grow, from year to year, until the stringency of the astronomical conditions became relaxed." *

In spite of the fact that this theory appears to be so complete, and to afford an explanation of several difficult points connected with the Glacial Period, it has failed to find favour with

* "The Cause of an Ice Age." Sir R. Ball.

a very considerable number of geologists. The latter do not venture to question the astronomical data which are supported by such high authority, or the existence of the changes in the orbit of the earth and its axis of rotation which have been deduced from them; but they do express doubt as to whether these changes could have had effects upon the climate of the globe, so profound, as those which have been claimed from them. A serious objection to the theory has been pointed out by Professor Bonney. From Dr. Croll's calculations it appears that a low temperature must have prevailed for nearly 3,000,000 years previous to the termination of the Ice Age, and have been marked by at least five Glacial Periods. But this interval of time, in all probability, embraced a considerable portion of early and middle Tertiary times, during which, as we have already seen, a warm climate prevailed. If we get over the difficulty by assigning the whole of the 3,000,000 years to the Glacial Period, we are obliged to give to the rest of the geological history of the earth an enormously longer interval of time than any geologist would be prepared to admit.

The explanations of the cause of the Glacial Period, which are based upon phenomena occurring upon the surface of the globe itself, assume generally changes in the amount of elevation of the land above the sea, or deviations in the direction of flow of the great ocean-currents. We have seen that the low

temperature of the upper layers of the atmosphere causes the summits of high mountains to be covered with snow, which ultimately creeps down their sides in the form of glaciers. It has been calculated that an elevation of about 6,000 feet in the north-west of Europe would produce probably a degree of cold as severe as that of the Glacial Period. There is, however, no evidence of such an elevation in past times. A change of this sort, moreover, would have caused land to appear in the Atlantic to the west of Europe, and this would have intercepted a large part of the snowfall.

The deflection of the Gulf Stream is a change far more likely to have taken place, and one which would undoubtedly have had a very considerable effect upon the climate of north-west Europe. We have already seen that England and other countries forming the western margin of Europe are, at the present day, abnormally warm, and enjoy a mean annual temperature, considerably higher than that which is experienced in other areas between the same parallels of latitude, or even further south. This beneficent influence upon the climate is brought about by that great ocean-current of warm water which has received the name of the Gulf Stream from the fact that it commences its northward journey in the Gulf of Mexico (Fig. 36). The still larger Equatorial Current, from which the Gulf Stream is derived, is formed in the Atlantic chiefly by the action of the

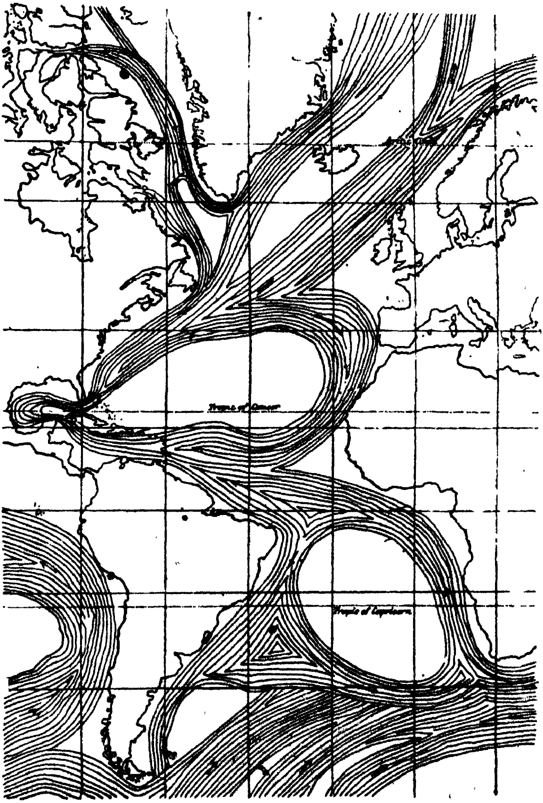

FIG. 36.—THE OCEAN-CURRENTS OF THE NORTH AND SOUTH ATLANTIC.

trade-winds. After starting from the African coast, and travelling right across the ocean, the current impinges upon the great easterly projection of the South American Continent, which terminates in Cape St. Roque. Here it is divided into two branches, but as the promontory lies rather to the south of the current, the two streams are very unequal, by far the larger quantity of water being turned northwards, while only a small current pursues its way down the Brazilian coast. The larger branch is driven along the northern coast of South America, through the Caribbean Sea into the Gulf of Mexico. Finding no exit here, it turns back, and flows out of the Gulf through the Straits of Florida; from this point it sweeps right across the Atlantic, bathing the coasts of Britain and Norway, and making its influence felt even as far north as Spitzbergen.

A little consideration will show that modifications in the geographical conditions, of no very great magnitude, might completely alter the direction of flow of the Gulf Stream. Suppose, for instance, that the projecting angle of South America lay to the north of the great Equatorial Current, the warm water would then be deflected into the Southern Ocean, and the Gulf Stream of the North Atlantic would cease to exist. A similar effect would be produced if the Equatorial Current, instead of flowing mainly north of the Equator, as it does at present, followed a path a few degrees to the south of that line.

Dr. Croll was of the opinion that a Glacial Period in the Northern Hemisphere, initiated by astronomical causes, would actually have the effect of compelling the Equatorial Current to flow south of its present position, the temperature being, in consequence, still further lowered. The effect of a difference in temperature between the North and South Pole is shown in the position of the Equatorial Current at the present day. The South Pole is colder than the North, and consequently the winds which blow from it, to replace the warm air which ascends from the Tropics, are stronger than those coming down from the north. In fact, the south-east trades of the Atlantic sometimes extend to 10° or 15° N. lat., whereas the north-east trades seldom blow south of the Equator. The warm water is, in consequence, impelled slightly northwards, and the current, instead of flowing across the Atlantic midway between the Poles, follows a path to the north of the Equator.

Another, and perhaps the most probable, way in which the Gulf Stream might have been interrupted, is by the opening of a passage in the narrow neck of land which links together the two American continents. The body of warm water would then flow straight out into the Pacific, and swell the Equatorial Current which traverses that ocean. Such a breaking of the barrier is very likely to have occurred, for the Isthmus of Panama and the West Indian Islands have yielded ample evidence of very considerable

changes of level within comparatively recent times.

But even if a deflection of the Gulf Stream were conclusively proved, it would not furnish us with an adequate cause for the Glacial Period. There is no doubt that the cessation would produce a marked fall in temperature over western Europe, amounting probably to between 7° and 8° in North Wales, and even more in Scotland and Norway. But Professor Bonney is of the opinion that a further reduction in temperature of at least 12° would be necessary to produce the degree of cold of the Ice Age.

From this brief review we see that there is no single explanation of the cause of the Ice Age which is entirely free from objection; and, in the present state of our knowledge, we are not justified in leaning to any particular view. It is possible that several influences were at work mutually aiding each other in bringing about the result, and it is in a favourable combination of comparatively small geographical and astronomical changes that we should, perhaps, seek for the cause of the Ice Age rather than in the operation of one agency. But it must be remembered that a satisfactory theory has to explain, not a change from the conditions of to-day to those of the ice age, but the far greater problem of the cooling of the tropical climate of Miocene times.

CHAPTER XIII.

TRACES OF ICE-WORK IN PERIODS EARLIER THAN THE ICE AGE.

A GLANCE at the table of the geological formations given on page 139 will show that the Glacial Epoch, to which we have hitherto confined our attention, forms quite a late chapter in the history of the globe. Are there any traces of ice-action among the rocks laid down during preceding ages? We have already traced the climate of Europe back to the commencement of the Tertiary period, and have seen that warm conditions were then prevailing. But this accounts for only a small part of the record. Though on paper the three main epochs, during which the pre-Quaternary rocks were being deposited, appear to have equal value and importance, this was by no means the case as regards the length of time over which they extended. The Tertiary period was far shorter than the Mesozoic, and this, in its turn, was greatly exceeded by the long Palæozoic period. During these countless ages glacial conditions might well have supervened on more than one occasion. As a matter of fact, phenomena, in the production of which the agency of land or sea-ice has been claimed,

have been found, at some place or other, in almost every one of the geological formations. But, with very few exceptions, they are susceptible of another and more probably correct explanation. In some formations rock-surfaces have been found exhibiting more or less scratching and polishing, and often associated with beds containing partially-rounded rock-fragments. These have been regarded as the work of glaciers, but in most cases other evidence has shown pretty conclusively, that they are to be attributed to movements in the rocks composing the solid crust of the globe. Sometimes boulders of a foreign rock have been found embedded in strata undoubtedly of marine origin. These may have been dropped from icebergs, but with equal probability they may have been floated away from land, firmly held by the roots of fallen trees. Even if the boulders were dropped from floating masses of ice they do not necessarily indicate the prevalence of glacial conditions. As we have seen, stones from Greenland are often carried long distances southwards before they are tumbled into the Atlantic. There is but one period anterior to the Ice Age of Quaternary times during which we can say, with any degree of certainty, that glacial conditions prevailed over a considerable area. In the Southern Hemisphere, the closing stage of the Palæozoic epoch appears to have been marked by a widely-spread lowering of temperature, the traces of which are now

met with in some of the warmest quarters of the globe.

Commencing with the oldest rocks, those of pre-Cambrian age, we find that certain conglomerates and sandstones of Scotland, and similar deposits in one or two localities of the United States, occasionally exhibit characters which bear a resemblance to those produced by glacial action. There is, however, very little doubt that the appearances in these cases have been produced by other agencies.

Among Palæozoic deposits, certain large boulders in the Cambrian rocks of Wales are possibly indications of ice-action. Greater certainty attaches to some phenomena first described by Dr. Reusch, and more recently re-examined by Mr. Aubrey Strahan, in the Varanger Fford, not far from the Russian and Norwegian boundary. Sandwiched in between two layers of sandstone is a mass of material presenting all the characters of true boulder-clay. It consists of an unstratified mixture of sand, grit and clay, containing boulders of all shapes and sizes ranging up to about two feet in length, some of them showing well-marked signs of glaciation. The underlying sandstone floor is also scratched and polished; and that this appearance extends beneath the boulder-clay, and is not merely the result of the recent passage of ice over the rock, Mr. Strachan made certain, "by wedging out some masses of that material, and exposing a fresh portion of the platform." * The exact

* *Quart. Journ. Geol. Soc.*, May, 1897.

geological position of these beds has not yet been determined, but they are undoubtedly of Palæozoic age.

There seems no reason to doubt that the phenomena seen in the Varanger Fiord are due to glacial action ; but occurring, as they do, in a locality so far north as latitude 70°, they cannot be regarded as indicative of an ice age in countries further south. They are, however, extremely interesting, as tending to show that even at that far-distant date, conditions within the Arctic circle could not have been very dissimilar from those which prevail there to-day.

In the south of Scotland, and in Ireland, beds of Lower Silurian age, have yielded boulders derived from rocks foreign to the district; but no traces of ice-markings have been found on them. A similar occurrence is recorded in deposits of the same age near Lake Superior, in North America. In the Old Red Sandstone of Scotland and the north of England, conglomerates not unfrequently occur which bear a considerable resemblance to glacial detritus. Often they are quite unstratified, while many of the stones are subangular and striated like those of morainic débris. Sir Andrew Ramsay suggested that these conglomerates might have been produced by the agency of glaciers or ice-sheets; but it is now generally admitted that they have been formed by the movement of one mass of rock upon another, fragments being broken off and ground down in the process.

Boulders which appear to have been brought from some distance, have been found in the Coal-measures of England and other parts of Europe, as well as in America. In Lancashire, they have been met with, upwards of 200 pounds in weight. These were all probably floated away from their original positions, entangled in the roots of trees.

In the Permian beds of the central counties of England, certain conglomerates occur which were considered by Sir Andrew Ramsay to point to the action of glaciers and icebergs. He based his conclusion upon, the distance of the source from which he believed the stones forming the conglomerate to have been derived; the large size and more or less rounded character of some of the stones; and the traces of scratching and polishing their surfaces occasionally exhibit. More recent investigation has shown that the distance the stones have travelled is not so great as was supposed; while the striations they exhibit are by no means typically glacial. In all probability these breccias or conglomerates were produced by streams flowing from high ground in the immediate vicinity, while according to Professor Bonney, the striations on the stones are the result of subsequent earth movements.

But in rocks of approximately the same age on the other side of the globe, in Australia, the Cape, South America, and even tropical India, striking discoveries of ice-action have been made, pointing to a general glaciation of the

Southern Hemisphere at the close of Palæozoic times. Before proceeding to discuss separately the evidence afforded by each country, it may be well to explain how it is that differences in the conditions under which the rocks were laid down have necessitated the employment of terms other than those used in the Northern Hemisphere.

The lines of division between the various geological systems have, in general, been drawn where a marked change occurs in the character of the rocks. These changes have been brought about by modifications in the geographical conditions, such as the submergence of a land-area beneath the sea and *vice versa*. Over the greater part of Europe, for instance, at the close of Carboniferous times extensive movement of upheaval and depression took place, converting the wide lagoons and swamps, in which the vegetation of the coal-fields flourished, into salt inland seas eminently unfavourable to life. In these land-locked lakes, deposits of salt were thrown down and sediments stained red with iron oxide, giving to the rocks of the Permian age characters quite distinctive from those of the Carboniferous system below. But in the Southern Hemisphere these geographical changes do not seem to have occurred, and, in consequence, no distinct line of separation can be drawn between the two formations. The upper beds of the Carboniferous period are accordingly grouped with those of Permian age under the name of Permo-Carboniferous.

It is these rocks which have yielded undoubted traces of a Palæozoic glacial period.

From South Australia, quite conclusive evidence of ice-action has recently been brought forward by Professor Edgworth David. Near Heathcote, glacial beds have been found between 300 and 400 feet in thickness consisting chiefly of hard and soft mud-stones containing erratics. Some of the latter are nearly thirty tons in weight, and many of them exhibit well-marked signs of glaciation, their surfaces being strongly grooved, polished, and facetted. The soft mud-stones consist chiefly of clayey material with comparatively few erratics; the hard mud-stones contain numerous glaciated boulders "frequently flattened on one side as though they had been rasped away by the ice." In size the erratics vary from a few inches to five and a half feet in diameter, thongh most of them are less than a foot across. Underlying these beds are rocks of Silurian age, the surfaces of which are also in places strongly scratched and polished; while above the mud-stones is a deposit of conglomerate composed of well-rolled pebbles with occasionally large, glaciated erratics. Still higher are sandstones exhibiting distinct evidence of contortion, and containing, in places, well-preserved traces of vegetation, the plants composing which belong to a remarkable group apparently unrepresented in rocks of the same age in the Northern Hemisphere. The total

thickness of the beds through which traces of glacial action have been found, cannot be less than 5,000 feet. They have been traced northwards as far as Springhurst, on the boundary between New South Wales and Victoria, while the polished and moutonée rock-surface at the base of the series extends over an area of 130 square miles. From the direction of the scratches and the sides on which the rocks are polished, it is inferred that the ice which produced these effects came from the south.

In Tasmania, New South Wales, and Queensland, similar deposits have been found apparently of the same age, showing that the glaciation was not a mere local occurrence, but extended over a large part, perhaps even the whole of Australia. It is interesting to note that remains of the group of plants present in the beds near Heathcote (known as the *glossopteris flora* from the name of one of the most abundant forms, have also been found at several of these localities, associated with glacial deposits.

In various parts of South Africa, deposits of Permo-Carboniferous age are found exhibiting phenomena which have almost undoubtedly been produced by glacial action. Both in Natal and in Cape Colony, a conglomerate is met with containing numerous large erratics and striated boulders, some of which appear to have been transported sixty or eighty miles from the parent mass of rock. Occasionally they are of large size, weighing five or six

tons and measuring six feet across. In addition, the surfaces of the Carboniferous rocks, which underlie the conglomerate, where exposed are generally seen to be grooved and polished, this apparently having been effected by ice travelling in a N. N. W. and S. S. E. direction. In beds above the conglomerate, remains of the Glossopteris group of plants have been discovered.

But, perhaps, the most striking discoveries of the traces of the Permo-Carboniferous Ice Age are those which have been made in India within only a few degrees of the Equator. In Bengal, and in the Central Provinces, there is a deposit known as the Talchir boulder-bed which has long been regarded as the work of ice. Some of the boulders measure six feet across, and exhibit well-polished and striated faces, while the surface of the rock, underlying the deposit, is similarly smoothed and scratched. The boulder-bed is of an extremely wide-spread nature, being found, in addition to the localities mentioned, in the Nerbudda Valley, the desert of Rajputana, and the Punjaub. In some localities it is succeeded by beds of sandstone, containing layers with numerous remains of the same plants as are present in the corresponding deposits of Australia and the Cape.

Besides the evidence furnished by India, South Africa, and Australia, traces of ice-action have been found in rocks of Permian-Carboniferous age in South Brazil and Argentina, and sometimes, in associated beds,

remains of the Glossopteris group of plants.

It is a somewhat remarkable fact that the glacial boulder-beds of the Southern Hemisphere should be so frequently succeeded by deposits containing such a peculiar and distinctive flora. The principal representative of the group, Glossopteris itself (Fig. 37), is

FIG. 37.—LEAF OF *Glossopteris*.

characterised by long, simple, undivided leaves with a midrib and net-like arrangement of veins. Others have pinnate or fan-shaped leaves. The peculiar nature of the flora as a whole, becomes evident when it is compared with the plants which flourished in Carboniferous and Permian times in European areas. The latter are almost completely

absent in the Southern Hemisphere, the plants there taking their place bearing a resemblance to forms which did not appear in the north until the later Mesozoic age. It has been suggested that the old Palæozoic vegetation was destroyed by the gradual cooling of the climate, and thus room was made for the newer forms. Mesozoic forms, in consequence, first appeared in the Southern Hemisphere, and flourished there, while the older vegetation continued to hold its ground in the northern half of the globe.

To sum up, then, there are in Australia, India, South Africa, and South America, numerous deposits all telling the same story of an extensive glaciation of the Southern Hemisphere during Permian-Carboniferous times; unaccompanied, so far as we know, by any corresponding decline of temperature in the northern half of the globe. That the period of cold was of prolonged duration is shown by the enormous thickness of the glacial beds in South Australia. The Permo-Carboniferous Ice Age is hidden too far back in the mists of time to enable us to come to any satisfactory conclusion as to its cause. It may be that it was brought about by a great extension of the South Polar ice-cap, or it may be that higher ground existed over the site of the southern seas from which huge glaciers crept northwards as far even as Central India. The disappearance of these lands, and the formation of the deep ocean which now rolls over them, may well have occurred during the

long succeeding geological ages. But the presence of glaciers in Central India, over an area now covered with dense forests and jungle, would seem to indicate an ice age more severe than that of the Quaternary epoch, and is difficult to explain, whatever theory be adopted.

In the succeeding deposits laid down during the Mesozoic and Tertiary periods, boulders of foreign rock have occasionally been found which should probably be attributed to the action of floating ice. The chalk of England for instance, has yielded fragments of granite, and, in one case, a mass of coal some four feet square. In the Eocene deposits of the Continent, certain beds occur which exhibit features recalling those produced by land ice. Other evidence, however, strongly negatives the suggestion. There are, in fact, above the beds of Permo-Carboniferous age, no further certain traces of glacial action until we meet with the striking series of deposits and other indications of land-ice formed during the Glacial Period in Pleistocene times.